JOURNAL OF THE A·I·E·E·

SEPTEMBER 1924

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American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Pasadena, Cal., October 13-17

Midwinter Convention, New York, N. Y., Feb. 9-13

MEETINGS OF OTHER SOCIETIES

Association of Edison Illuminating Companies, New London, Conn., Sept. 8-12

Association of Iron & Steel Electrical Engineers, Pittsburgh, Pa., Sept. 15-20

American Mining Congress, Sacramento, Cal., Sept. 29—Oct. 4

American Elec. Rwy. Assn., Atlantic City, N. J., Oct. 6-10

Inst. of Metals Div., American Institute Mining & Metallurgical Engrs., Milwaukee, Wis., Oct. 11-18

American Electrochemical Society, Detroit, Mich., Oct. 2-4

Empire State Gas & Electric Assn., Lake Placid Club, N. Y., Oct. 6-7

Illuminating Engineering Society, Briarcliff Manor, N. Y., Oct. 27-31

JOURNAL

OF THE

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Current Electrical Articles Published by Other Societies

American Welding Society, June, 1924

Standards for Arc Welding Apparatus, Bull. No. 3, 7 pp.

Electric Welding of Large Storage Tanks, by H. C. Price, pp. 11-21

Iron & Steel Engineer, July, 1924

Mechanical and Electrical Analyses of 40-Inch Blooming Mill Screwdown, by F. D. Egan, pp. 371-9

Giant Power Survey of Pennsylvania, by J. C. Dickermann, pp. 279-82

National Electric Light Assn. Bull., July, 1924

Report of Public Policy Committee, by M. J. Insull, pp. 440-6

Giant Power, by G. Pinchott, pp. 424-5

Physical Review, July, 1924

Currents Limited by Space Charge between Concentric Spheres, by I. Langmuir and K. B. Blodgett, pp. 49-59

Theory of Thermionics, by H. A. Wilson, pp. 38-48

Electromagnetic Induction in a Homogeneous Solid Conducting Sphere Rotating about an Axis Perpendicular to a Uniform Alternating Magnetic Field, by A. Marcus, pp. 68-78

Method of Producing a Square Wave of Radio Frequency, by J. L. Bowman, pp. 31-7

Transactions, Illuminating Engineering Society, July, 1924

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Central Station Practise in Europe, by B. G. Jamieson, pp. 247-56

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Third National Radio Conference

Secretary Hoover of the Department of Commerce recently called the Third National Radio Conference for the better voluntary regulation of radio, to be held in Washington, D. C., beginning September 30th.

Two such conferences have already been held, one in February, 1922, and one in March, 1923, both of which were generally attended by the persons and organizations interested. The result has been a lessening friction and misunderstanding through the voluntary cooperation of the industry, the public and the Department of Commerce, especially in the reduction of interference and the improvement of service.

The growth of radio and particularly the multiplication of broadcasting stations and the consequent congestion of the air has made necessary a consideration of many subjects and perhaps a revision of some present methods. Some of the matters which will be discussed and considered at the Conference are:

Revision of the present frequency or wave length allocations, to reduce interference.

Use of high frequencies or short waves.

Classification of broadcasting stations; possible discontinuance of Class C stations.

Interconnection of broadcasting stations.

Limitation of power; division of time; zoning of broadcasting stations.

Means of distinguishing the identity of amateur calls from foreign countries.

Interference by electrical devices other than radio transmitting stations.

Relations between government and commercial services.

Such other topics as may be proposed by the Conference.

To facilitate the work of the Conference the various groups in the radio field will be asked to name representatives who will constitute the formal advisory committee of the Conference. As at present planned, the groups to be represented will be as follows: listeners, marine service, broadcasting, (one from each inspection district); engineering, transoceanic communication, wire inter-connections, manufacturers, amateurs, point-to-point communication, government departments.

The committee so constituted will hold public hearings. All persons or organizations having any suggestions to make or views to express upon any features of radio activity are urged to attend and will have full opportunity to be heard.

Some of the matters suggested for consideration are not within the regulatory control of the Secretary. As to such matters, any conclusions reached by the Conference can become effective only by voluntary adoption by the interest affected. As to the features falling within the powers of the Secretary the recommendations of the Conference will be advisory to the Department.

Contents of the A. I. E. E. Journal

For several months past the JOURNAL has contained letters from members of the Institute, giving various opinions as to the most desirable class of papers which should appear in the JOURNAL, and letters of this kind are being received in such numbers that it is impossible to give them space, in view of the seriously overcrowded conditions of publication which have existed for many months.

These letters may roughly be divided into three general classes, namely, those desiring more technical papers, those desiring less technical papers, and those expressing appreciation of the present make-up of the JOURNAL.

Criticisms of some of our correspondents who desire to see nothing in the JOURNAL except the highly technical articles and who claim that its present contents are too popular and elementary, are not entirely fair. While it has been the aim of the Publication Committee to include a certain amount of so-called popular material in the JOURNAL, the Committee has never been able to do so, for the reason that the papers presented at our four Conventions have been so numerous and of such length as to crowd out practically everything else. For the last year the JOURNAL has been filled almost exclusively with the papers presented at our four national meetings and if these are not sufficiently technical to suit some of our readers, this fault cannot be attributed to the JOURNAL. The only real change which has been made in the contents of the JOURNAL in the past year is the publication of some of the longer papers in abridged form and the omission in some cases of the mathematical appendices, and even in the case of these abridged papers, complete copies are available on request free of charge, so that nothing has been withheld from JOURNAL readers that they have formerly been accustomed to receive.

The annual appropriation for the publication of the JOURNAL covers an estimated volume of about 1000 pages per year, and so long as our four conventions supply four or five hundred pages more than our appropriation covers, there is but little opportunity for changing the publication policy now in force.

Some Leaders of the A. I. E. E.

Alexander Graham Bell, seventh President of the American Institute of Electrical Engineers, is most widely known as the inventor of the telephone. To a large circle of personal and professional friends he was equally well known for the many other activities of his life, so largely devoted to the service of mankind. His work for the deaf, his scientific researches in the field of heredity and eugenics, his experiments in aeronautics, his work in improving the phonograph, his invention of the surgical telephone probe and of the photophone illustrate the scope of his mind.

Dr. Bell was born on March 3, 1847, in Edinburgh, Scotland. He attended the University of Edinburgh and University College, London. In 1868 he adopted a system of so-called "visible speech" which had been developed by his father to the teaching of deaf children in a school in London. Thus early he started his work for the deaf, which was a dominant motive throughout all his life.

In 1870 he came to America with his parents, who settled in Canada, and the next year at the age of 24 he moved to Boston. After introducing into a number of American schools for the deaf improved methods of teaching deaf mutes to speak, he was appointed a Professor in the School of Oratory at Boston University. In his spare time he conducted experiments, particularly on the electrical transmission of signals and vocal sounds. From this there developed in 1875 the epoch-making invention of the telephone.

In 1880 the French Government, in recognition of his invention of the telephone, made Dr. Bell an officer of the Legion of Honor, and awarded him the Volta Prize of 50,000 francs. With this money he founded the Volta Laboratory for scientific research and invention. From this laboratory and the Volta Bureau for the Deaf which grew out of it, came many subsequent achievements of his life.

Dr. Bell died at his summer home near Baddeck, on Bras d'Or Lakes, Cape Breton Island, August 2, 1922, and was buried on a mountain overlooking the lakes.

Dr. Bell founded the American Association for the Promotion of Teaching Speech to the Deaf. He was a member of nearly fifty scientific, educational, and medical organizations in America and abroad. In many of these he had been elected to honorary membership. Among the associations of which he was a member are the American Institute of Electrical Engineers, the National Academy of Science, the American Philosophical Society, the American Academy of Arts and Sciences, the American Association for the Advancement of Science. He was a trustee, and at one time President of the National Geographic Society, and was a Regent of the Smithsonian Institution.

Among the honorary degrees conferred upon Alexander Graham Bell were the following: Ph. D., Wurzburg University, 1882; M. D. University of Heidelberg (Germany), 1886; LL. D., Harvard College, 1896; LL. D., Amherst College, 1901; LL. D., St. Andrew's University (Scotland), 1902; LL. D., Edinburgh University (Scotland), 1906; Sc. D., Oxford University (England), 1907; LL. D., Queen's University (Canada), 1909; LL. D., George Washington University, 1913; LL. D., Dartmouth College, 1913.

Dr. Bell had the satisfaction within his own lifetime of seeing his invention of the telephone develop into vast communication systems. It was in March, 1876, over a line extending between two rooms in a building in Boston that the first complete sentence was spoken and heard over an electrical telephone. It was spoken by Dr. Bell, and heard by his assistant, Mr. Watson. It consisted of these words: "Mr. Watson, come here. I want you." In January, 1915, Dr. Bell, using a reproduction of his original instrument, once again spoke the words, "Mr. Watson, come here. I want you," but this time Dr. Bell was in New York, and Mr. Watson, who heard him with perfect ease, was over 3000 miles away in San Francisco.

Studies of High-Voltage Transmission for Fall Convention

A remarkable group of contributions on many phases of high-voltage transmission will be presented at the coming Fall Convention in Pasadena. A large number of papers covers practically every side of this subject from the speculative, through laboratory and field studies of highly technical as well as practical nature, to the actual operating practise and economic and managerial features.

Of particular interest will be the studies on corona. Methods of measurement have been developed to such a state of perfection that field tests on the high-voltage lines have been made with an accuracy which compares well with that obtained formerly only in laboratory measurements. These contributions include these field measurements as well as laboratory tests on the nature of corona. Some of the contributions go a step further and reduce the values of corona losses to practical economic quantities. Incidentally, it is of interest that one of the contributions suggests that this bugbear, corona, may be put to useful work as a protector of transmission lines against surges and lightning.

Some of the latest studies on the nature and effects of lightning and on the development of insulators for extremely high voltages naturally form a part of this group of contributions. Some almost radical means of line insulation will be discussed.

Theory and Calculation of the Squirrel Cage Repulsion Motor

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Associate, A. I. E. E.

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Review of the Subject.*—A brief history of the development of the squirrel cage repulsion motor and a physical explanation of the principles of its operation have been given in the preceding paper "A New Type of Single Phase Motor" by Mr. S. R. Bergman. It is the purpose of the present paper to give the results of an analytical study of the operation of the motor. The derivation of the method of calculation is outlined and some of the more interesting results are given.*

THE only known method that has thus far been worked out for the calculation of the performance characteristics of the squirrel cage repulsion motor is a method which has been derived from an analytical solution of the fundamental voltage equations in a manner similar to the method given by Steinmetz[1] in his general equations for a-c. motors. The method that has been developed differs somewhat from that given by Steinmetz in the form and arrangement of the results. As a result of this difference in the treatment, not only was a workable method worked out for the calculation of the performance characteristics of the squirrel cage repulsion motor, but it was also found that accurate and useful methods for calculation of performance characteristics of different types of a-c. motors, such as, for instance, the double squirrel cage induction motor, could be worked out along similar lines. The derivation of the method of calculation will therefore be explained in the hope that similarly derived methods may be found useful in the study of other types of machines.

The squirrel cage repulsion motor, as described by Mr. Bergman, consists of a repulsion motor with a squirrel cage placed well below the commutated rotor winding. The brushes are set at a larger angle, usually about 30 electrical degrees, from the neutral axis than in the case of the plain repulsion motor. The amount of copper in the commutated winding and the size of the commutator and brushes of a squirrel cage repulsion motor are less than in a repulsion motor, since the squirrel cage carries part of the rotor current. The construction is otherwise essentially the same as that of a plain repulsion motor. The relation of the squirrel cage to the commutated winding is indicated in Fig. 1.

In the following, it will be assumed that all m. m. fs. and fluxes are sinusoidally distributed in space. In order to further simplify the solution, the angle of hysteretic lag between flux and m. m. f., and the effect of the local currents in the coils short-circuited by brushes are neglected. In calculation of losses the core loss can be calculated separately and considered either as extra input, or as a frictional drag, or as partly extra input and partly frictional drag. The motor operates at speeds near synchronism throughout its normal operating range where the currents induced in the coils short-circuited by the brushes are negligible. The effect of these currents is therefore neglected in the general equations. These assumptions effect a considerable simplification in the solution of the equations, which in its present form is at best too complicated for general routine design work.

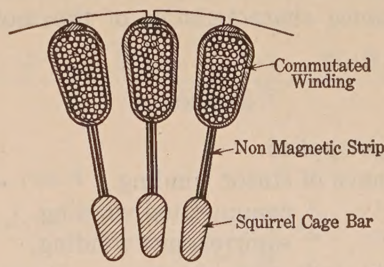


Fig. 1

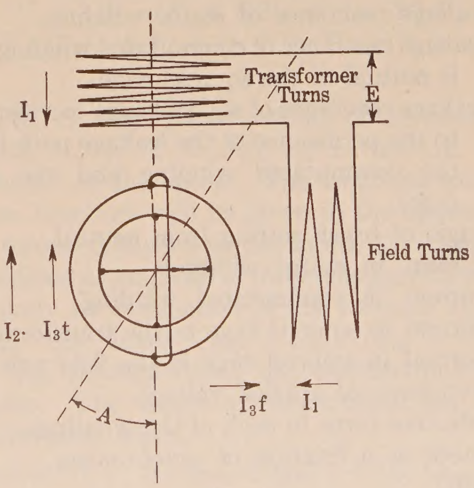


Fig. 2

Following the usual treatment of the plain repulsion motor, the stator winding of the squirrel cage repulsion motor is resolved into two component windings whose axes are at right angles to each other; the transformer winding whose axis, called the transformer axis, coincides with that of the commutated winding as deter-

1. Theory and Calculation of Electrical Apparatus, Chapter 19.

Presented at the Annual Convention of the A. I. E. E., Edgewater Beach, Chicago, Ill., June 23-27, 1924.

mined by the brush position; and the field winding whose axis is at right angles to that of the commutated winding. In accordance with the assumption of sinusoidally distributed m. m. fs., the number of effective turns in the transformer and field windings is equal to the effective turns of the stator winding as a whole, multiplied by the cosine and sine, respectively, of the angle formed by the magnetic axis of the commutated winding, as determined by the brush position, with the magnetic axis of the stator winding.

The squirrel cage can be considered as equivalent to a commutated winding, the corresponding brushes of which are short-circuited in two rectangular axes. For purposes of analysis, the motor can therefore be considered as consisting of four simple circuits; the stator circuit, the commutated winding, and the two equivalent circuits of the squirrel cage. The motor can be represented diagrammatically as in Fig. 2. By applying Kirchoff's Law to these four circuits, we obtain four simultaneous equations, from the solution of which the performance characteristics of the motor can be determined.

Symbols

E = voltage applied.
r_1 = resistance of stator winding.
r_2 = " " commutated winding.
r_3 = " " squirrel cage winding.
X_m = mutual inductive reactance corresponding to flux mutual to all three windings.
x_1 = leakage reactance of stator winding.
x_2 = leakage reactance of commutated winding (which is mutual to the squirrel cage).
x_3 = leakage reactance of squirrel cage (corresponding to the permeance of the leakage path between the commutated winding and the squirrel cage).
A = angle of brush setting from neutral.
I_1 = current in stator winding.
I_2 = current in commutated winding.
I_{3t} = current in squirrel cage in the transformer axis.
I_{3f} = current in squirrel cage in the field axis.
f = frequency of applied voltage.
N = effective turns in each of the windings.
S = speed as a fraction of synchronism.
s = slip.
ω = $2\pi f$.
σ = $S\omega$ = "angular speed."

The resistances and reactances should all be expressed in terms of the number of turns in the stator winding. The symbols for voltage and current all represent time vector quantities. The positive senses of the currents are indicated by the arrows in Fig. 2.

The fluxes linking the four circuits of the motor can be resolved into mutual and leakage components which can be expressed in terms of the various reactances and currents as follows:

The transformer flux ϕ_{mt} which is the component of the mutual flux of stator and rotor in the transformer axis,

$$\phi_{mt} = \frac{X_m}{2\pi f N}(I_1 \cos A - I_2 - I_{3t}) \quad (1)$$

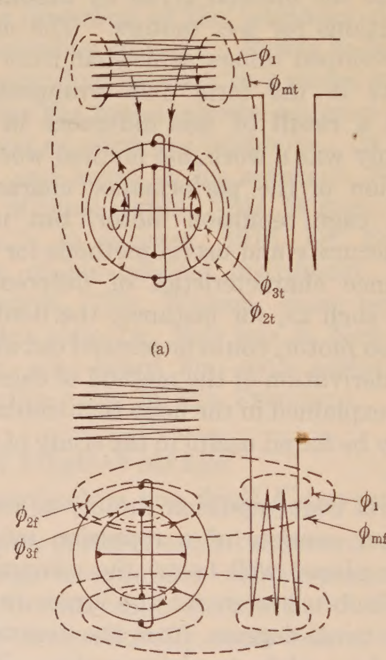
The field flux ϕ_{mf} which is the component of the mutual flux of stator and rotor in the field axis,

$$\phi_{mf} = \frac{X_m}{2\pi f N}(I_1 \sin A - I_{3f}) \quad (2)$$

The leakage flux of the primary,

$$\phi_1 = \frac{x_1 I_1}{2\pi f N} \quad (3)$$

The leakage flux linking the commutated winding in the transformer axis,



(b)

Fig. 3

$$\phi_{2t} = \frac{x_2(I_2 + I_{3t})}{2\pi f N} \quad (4)$$

The leakage flux cut by the conductors of the commutated winding in the field axis,

$$\phi_{2f} = \frac{x_2 I_3 f}{2\pi f N} \quad (5)$$

The leakage fluxes in the transformer and field axes respectively, linking the squirrel cage conductors only,

$$\phi_{3t} = \frac{x_3 I_{3t}}{2\pi f N} \quad (6)$$

$$\phi_{3f} = \frac{x_3 I_{3f}}{2\pi f N} \quad (7)$$

The relations of these flux components to the circuits and to each other are indicated in Figs. 3a and 3b.

Voltage applied to the stator terminals must overcome the resistance drop $r_1 I_1$ and the voltages induced by alternation of ϕ_1, ϕ_{mt} and ϕ_{mf}. That is,

$$E = r_1 I_1 + j\,2\,\pi f\,(N\,\phi_1 + N\,\phi_{mt}\cos A + N\,\phi_{mf}\sin A)$$

Substituting for the fluxes their values given in equations (1), (2) and (3), we have,

$$E = r_1 I_1 + j\,x_1 I_1 + j\,X_m \cos A\,(I_1 \cos A - I_2 - I_{3t}) + j\,X_m \sin A\,(I_1 \sin A - I_{3f}) \qquad (8)$$

In the commutated winding, voltage is induced by transformer action of ϕ_{2t} and ϕ_{mt}, and by rotation through ϕ_{2f} and ϕ_{mf}. The vector sum of these voltages must equal the resistance drop $r_2 I_2$. This gives the equation,

$$O = r_2 I_2 - j\,2\,\pi f N\,(\phi_{mt} + \phi_{2t}) + S\,2\,\pi f N\,(\phi_{mf} + \phi_{2f})$$

or

$$O = r_2 I_2 - j\,X_m(I_1 \cos A - I_2 - I_{3t}) + j\,x_2\,(I_2 + I_{3t}) + S\,X_m\,(I_1 \sin A - I_{3f}) - S\,x_2 I_{3f} \qquad (9)$$

Similarly, for the squirrel cage in the transformer axis,

$$O = r_3 I_{3t} - j\,X_m\,(I_1 \cos A - I_2 - I_{3t}) + j\,x_2\,(I_2 + I_{3t}) + j\,x_3 I_{3t} + S\,[X_m\,(I_1 \sin A - I_{3f}) - (x_2 + x_3)\,I_{3f}] \qquad (10)$$

and in the field axis,

$$O = r_3 I_{3f} - j\,X_m\,(I_1 \sin A - I_{3f}) + j\,(x_2 + x_3)\,I_{3f} + S\,[-\,X_m\,(I_1 \cos A - I_2 - I_{3t}) + x_2\,(I_2 + I_{3t}) + x_3 I_{3t}] \qquad (11)$$

The above four equations, (8), (9), (10) and (11) containing the four unknowns I_1, I_2, I_{3t} and I_{3f} can be solved giving equations from which the performance characteristic curves of the motor can be calculated.

It will be noted that these equations differ in form from the general equations of Steinmetz[2] for a-c. motors having any number of windings in both stator and rotor, in that his equations do not contain terms corresponding to $S\,x_2 I_{3f}$ in equation (9), $S\,(x_2 + x_3)\,I_{3f}$ in equation (10), and $S\,[x_2\,(I_2 + I_{3t}) + x_3 I_{3t}]$ in (11). In his treatment of polyphase motors, he took care of the phenomena involved by considering the leakage reactance of the rotor windings as being proportional to the slip. This gives exactly the same results, and is an exactly equivalent method when applied to polyphase motors. However, in cases where the mutual flux of stator and rotor is resolved into two components at right angles to each other in space, it seems preferable to treat the leakage flux in the same way and not to consider it as a flux revolving at synchronous speed. This applies particularly to the case of commutator motors where the current in the individual conductors is of line frequency. In single-phase motors where the leakage reactances of the rotor windings cannot in general be considered proportional to the slip, the omission of the terms representing voltages induced by rotation of rotor conductors through leakage fluxes results, in the usual case, in slight and negligible inaccuracies, but in the case of the squirrel cage repulsion motor would result in inaccuracies so great as to completely destroy the value of the results.

It is of interest to note that the reasoning on which the above equations are based is exactly similar to that followed by Arnold[3] in formulating the fundamental equations from which he developed the equivalent circuit for the single-phase induction motor according to the cross field theory.

Rearranging terms in equations (8) to (11) and solving for I_1, I_2, I_{3t} and I_{3f}, we get equations of the following forms:

$$I_1 = E\,\frac{F_1 + (1 - S^2)\,F_2 + j\,[F_3 + (1 - S^2)\,F_4]}{U + j\,W} \qquad (12)$$

$$I_2 = E\,X_m \cos A \left(\frac{G_1 + S\,G_2 + (1 - S^2)\,G_3 + S\,(1 - S^2)\,G_4 + j\,[G_5 + S\,G_6 + (1 - S^2)\,G_7]}{U + j\,W}\right) \qquad (13)$$

$$I_{3t} = E\,X_m \cos A \left(\frac{H_1 + (1 - S^2)\,H_2 + S\,(1 - S^2)\,H_3 + j\,H_4}{U + j\,W}\right) \qquad (14)$$

$$I_{3f} = E\,X_m \cos A \left(\frac{S\,J_1 + (1 - S^2)\,J_2 + j\,[J_3 + (1 - S^2)\,J_4]}{U + j\,W}\right) \qquad (15)$$

where

$$U + j\,W = F_5 + S\,F_6 + (1 - S^2)\,F_7 + j\,[F_8 + S\,F_9 + (1 - S^2)\,F_{10} + S\,(1 - S^2)\,F_{11}] \qquad (16)$$

and F_n, G_n, H_n and J_n are functions of the motor design constants, r_1, r_2, r_3, X_m, x_1, x_2, x_3, and A, and are independent of the speed. The complete expressions for these functions will be given in the appendix.

The torque produced by the motor at any speed can be considered as made up of three components produced respectively by interaction of the currents I_2, I_{3t} and I_{3f} with the fluxes $(\phi_{mf} + \phi_{2f})$, $(\phi_{mf} + \phi_{3f})$, and $(\phi_{mt} + \phi_{3t})$ through which the corresponding conductors rotate. The torque of the motor at any speed is, in synchronous watts:

$$T = 2\,\pi f N\,\{\,[\,(I_2\,(\phi_{mf} + \phi_{2f})\,] + [I_{3t}\,(\phi_{mf} + \phi_{3f})\,] + [I_{3f}\,x\,(\phi_{mt} + \phi_{3t})\,]\,\} \qquad (17)$$

where the expressions $[I_2\,(\phi_{mf} + \phi_{2f})\,]$ etc., represent the products of the in-phase components of current and flux. Substituting for the fluxes and currents their values according to equations (5), (6), (7), (13), (14) and (15) we get the following equation.

$$T = \frac{E^2 X_m{}^2 [M_1 + S\,M_2 + (1 - S^2)\,M_3 + S\,(1 - S^2)\,M_4 + (1 - S^2)^2\,M_5 + S\,(1 - S^2)^2\,M_6]}{U^2 + W^2} \qquad (18)$$

2. Loc. cit. 1.

3. Wechselstromtechnik, V. I. Chapter 8.

where M_1, M_2, etc., are functions of the motor design constants. The complete expressions for these functions will be given in the appendix.

By the use of suitable calculation forms, the torque developed and the current taken by the motor at any speed can be readily calculated from equations (**12**) and (**18**). Since the value of current obtained by solution of (**12**) is given in terms of its power and reactive components, the power factor and input can then be determined. From the torque and speed, the output is determined; then after allowing for friction and core losses the efficiency is determined. If it is desired, the currents I_2, I_{3t} and I_{3f}, and the corresponding components of the torque can be calculated in a similar manner.

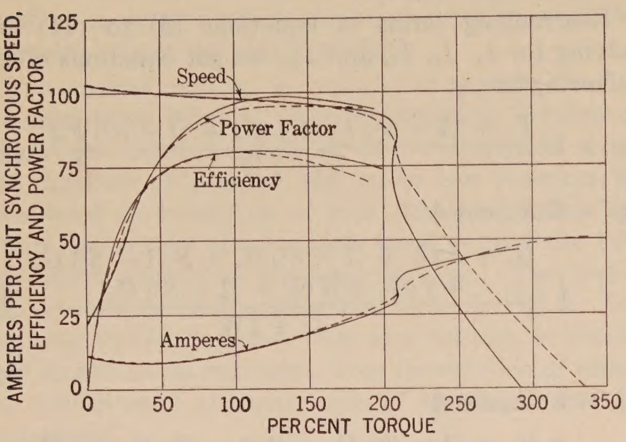


Fig. 4—Performance Curves of S. C. R. Motor
Motor-rated 3-h. p. 1800-rev. per min.
220-Volt 60-Cycle
Calculated values————
Tested values - - - - - - -

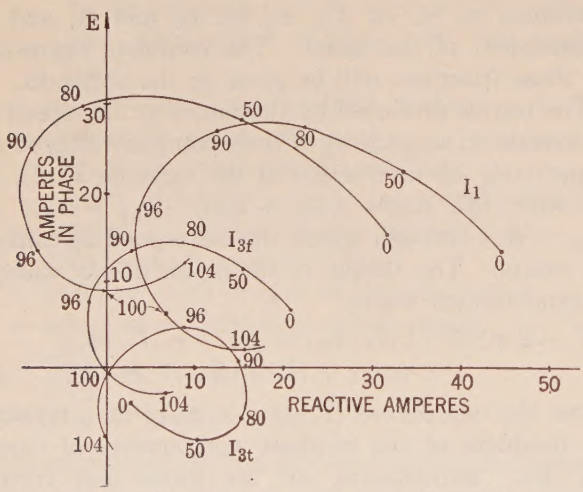


Fig. 5—Current Loci of S. C. R. Motor

In Fig. 4 are shown the performance characteristics of a 3-h. p. 1800-rev. per min. 60-cycle squirrel cage repulsion motor as calculated from equations (**12**) and (**18**). Tested values are shown for comparison in the broken curves. It will be observed that the motor has a starting torque of approximately three times full load torque, and for speeds from standstill up to about 90 per cent of synchronism has a speed torque characteristic similar to that of a plain repulsion motor. For speeds in the neighborhood of synchronism the speed torque characteristics are those of an induction motor, from no load to double load. The motor therefore combines the characteristics of a repulsion motor and of an induction motor in operation, as well as in mechanical construction. The power factor at full load and overload is seen to be from ten to fifteen per cent higher than would be obtained from either a plain repulsion motor or a plain single-phase induction motor of the same rating.

In Fig. 5 are shown the loci of the current vectors of the same motor, calculated from equations (**12**) to (**15**). The speeds corresponding to the different values of current are indicated in terms of synchronous speed on the curves. It will be observed that the stator

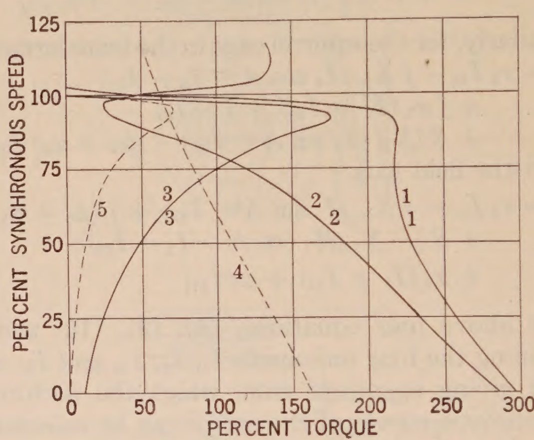


Fig. 6—Division of Torque Between Rotor Windings of S. C. R. Motor (Calculated Values)

1. Total Torque Developed by Motor.
2. Torque Developed by Commutated Winding Currents.
3. Torque Developed by Squirrel Cage Currents.
4. Torque that Would be Developed if Squirrel Cage were Removed.
5. Torque that Would be Developed if Comutated Winding were Removed.

current has its minimum value at synchronous speed, and that the variation in power input with change in speed in the close neighborhood of synchronism is accounted for principally by variation in power factor and not by variation in the magnitude of the current.

At full load, the current in the commutated winding is equal to approximately 85 per cent of the current in the stator winding.

The current I_{3t} in the transformer axis of the squirrel cage is very small for starting conditions, the squirrel cage in this axis being effectively shielded by the commutated winding. In the field axis, the squirrel cage current I_{3f} has its maximum value at standstill. For normal operating speeds, these currents I_{3f} and I_{3t} are approximately equal in magnitude and 90 deg. out of phase in time, I_{3f} leading I_{3t}.

The division of the torque between the commutated and squirrel cage windings is shown in the calculated

curves of Fig. 6. The speed torque curves of the motor when running with only the squirrel cage in the rotor, and with only the commutated winding, are shown in the dotted curves. It will be noted that the torque developed in the squirrel cage is roughly twice that which would be developed if the commutated winding were removed. In a general way, this is explained by the fact that for speeds in the neighborhood of synchronism, the motor has a nearly uniform revolving field like that of a polyphase induction motor. The explanation for this revolving field is the same as for the plain repulsion motor. That is, since the brushes bearing on the commutator are short-circuited, it follows that the voltages induced in the commutated winding by alternation of the transformer flux and by rotation through the field flux must be approximately equal. The transformer and field fluxes must therefore be 90 deg. out of phase in time as well as being at right angles in space. The resultant flux is therefore a revolving flux produced largely by the m. m. f. of the stator and commutated winding currents, independently of the squirrel cage currents. The squirrel cage therefore operates much the same as if it were in a polyphase motor, and it may be said to develop polyphase motor torque, the maximum torque thus developed being, roughly, twice the maximum torque that would be developed if the commutated winding were not used. For this reason the squirrel cage is much more effective at speeds in the neighborhood of synchronism than at standstill, and although the squirrel cage reactance is high enough so that the standstill conditions are comparable to those in a plain repulsion motor, the torque developed at speeds near synchronism is sufficiently large to give excellent speed regulation and to hold the no load speed to a value very slightly above synchronism.

The curve of torque developed by the commutated winding currents is of the same general shape as that of a plain repulsion motor, excepting in the neighborhood of synchronous speed where it has a definite maximum and minimum. The peculiar shape of this speed torque curve in the region of synchronous speed is of little practical significance or interest, except that it calls attention to the fact that the action of the commutated winding is greatly affected by the action of the squirrel cage current and vice versa, and that it is associated with the question of phase relations of the field flux, which, in turn, determine the power factor. This variation in torque is not due to any material change in the magnitude of the commutated current I_2 or the flux, $(\phi_{mf} + \phi_{2f})$, with which it reacts to produce torque, but is caused almost entirely by variation of the phase difference between the current and the flux.

When the motor is running at exact synchronous speed, the current in the squirrel cage can, for all practical purposes be considered equal to zero. The motor is therefore operating with the same current, power factor, efficiency, and torque as though the squirrel cage was removed, or, in other words, as a plain repulsion motor. If the load on the motor is increased so that the speed drops slightly below synchronism, currents are induced in the squirrel cage and induction motor torque is developed. The effect of these currents, as pointed out by Mr. Bergman, is to cause the field flux to lag the line current in time phase, resulting in power-factor compensation. That this phase difference is considerable for loads in the neighborhood of full load is shown by the fact that the torque produced by the commutated winding drops to a very low value.

At exact synchronous speed, the squirrel cage repulsion motor may be said to operate exactly the same as a plain repulsion motor, since the current in the squirrel cage is then practically zero. A plain repulsion motor operating with the same brush position will be found to develop at synchronous speed a torque equal to

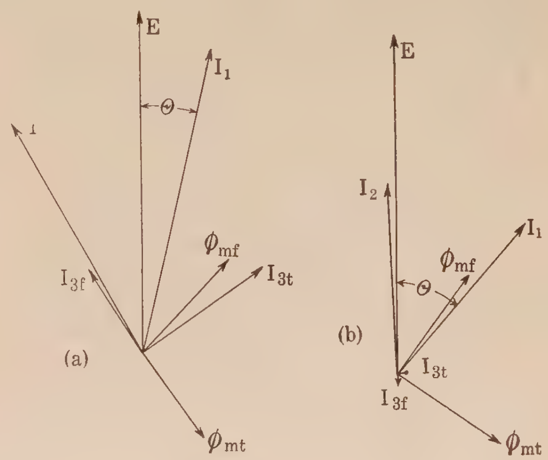


Fig. 7—Vector Diagrams of S. C. R. Motor

a. Full Load.
b. Synchronous Speed (Approximately Half Load.)

approximately 50 per cent of the rated full-load torque of a squirrel cage repulsion motor of the same design constants. It is evident then that the squirrel cage repulsion motor develops approximately 50 per cent of full-load torque at exact synchronous speed, and for all loads greater than half load, the speed is below synchronism, so that power-factor compensation is obtained for all loads throughout the most important range.

Vector diagrams showing the phase relations at synchronism and at full load are shown in Fig. 7.

In a properly designed squirrel cage repulsion motor the ratios of the resistance and leakage reactance of the squirrel cage to the resistance and leakage reactance of the commutated winding must be held within fairly close limits. In order to obtain the best starting torque per ampere of starting current, the squirrel cage reactance should be as high as possible. On the other hand, the higher the impedance of the squirrel cage, the higher will be the running free speed at which

the generator torque, developed by the squirrel cage, will neutralize the motor torque, developed by the commutated winding. The currents, and therefore the losses, will be found to be correspondingly higher, so that we may say that the higher the squirrel cage reactance, the higher the no-load losses. There is a narrow range of values of squirrel cage reactance for which the starting conditions are comparable to those of

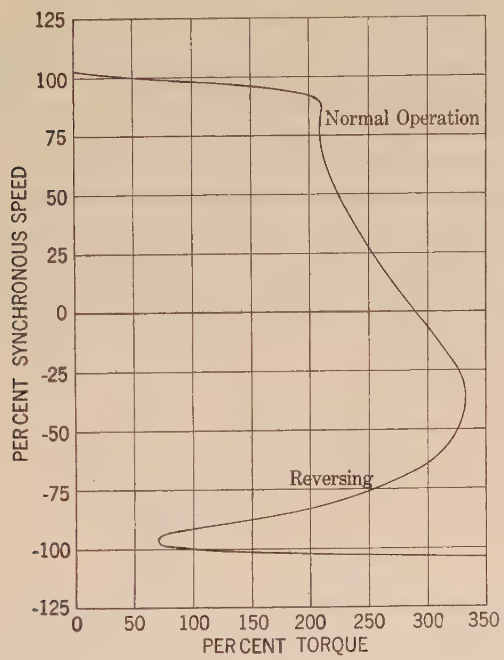


Fig. 8—Speed-Torque Curve of S. C. R. Motor for Positive and Negative Speeds

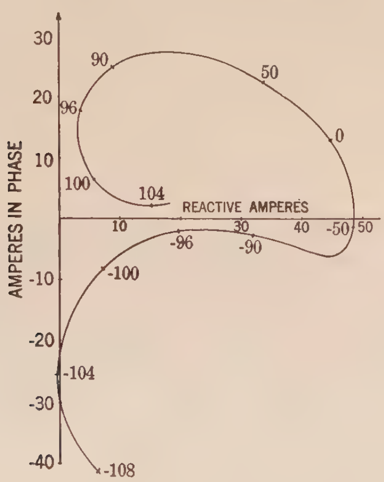


Fig. 9—Locus of Line Current—S. C. R. Motor

a plain repulsion motor, and the no-load losses will be well within reasonable limits.

Since the full-load torque of the motor is furnished largely by the squirrel cage, it is evident that the speed regulation must be roughly proportional to the slip. The resistance of the squirrel cage should therefore be reasonably low in order to give good speed regulation.

A squirrel cage repulsion motor for reversing service may be obtained by providing a stator with distinct transformer and field windings, one of which can be reversed; or if desired, reversal may be accomplished by shifting the brushes. The reversing characteristics of the motor are shown in Fig. 8, which is the speed torque curve for both positive and negative speeds, and in Fig. 9, which is the locus of the stator current vector.

The current locus shows that although the motor does not return power to the line when driven at a speed above its no-load speed, it does operate as a generator with good characteristics, if driven at approximately synchronous speed against its normal direction of rotation as a motor. Its efficiency as a generator under these conditions is practically the same as its efficiency as a motor in normal operation, and as shown by the current locus, the power factor may be very high. The commutating conditions in this region also compare with those in normal motor operation, the explanation being the same as in the case of motor operation, that is, the voltages in the commutated winding induced by transformer action of and rotation through the transformer and field fluxes are approximately equal, and therefore the transformer and field fluxes must be approximately equal in magnitude and 90 deg. out of phase in time, giving as a resultant a rotating field, revolving with the rotor and therefore giving practically the same commutating conditions as in normal motor operation. A squirrel cage repulsion motor can therefore be reversed while running at full speed with no trouble from commutation. As shown by the current locus, the current taken by the motor is only very slightly greater at certain speeds during reversal than at starting.

It is well known that the current in an individual conductor of the rotor of a plain single-phase induction motor consists of two components of different frequencies, one component being of slip frequency and the other of approximately twice line frequency. The amplitude of the double frequency component is greater than that of the slip frequency component. In the squirrel cage repulsion motor, the current in an individual squirrel cage conductor also consists of two components, but in this case the double frequency component is small in comparison to the slip frequency component. This is to be expected, since the mutual flux of stator and rotor is, roughly speaking, a revolving field produced largely by the m. m. f. of I_1 and I_2 independently of the squirrel cage currents. The conditions affecting the squirrel cage can be compared with those affecting the rotor of a polyphase induction motor with slightly unbalanced voltage applied to the stator; that is, the mutual flux of stator and rotor consists of a uniform revolving flux with a small pulsating flux superimposed in one axis. The ratio of the amplitude of the slip frequency component of current to the double frequency component, which is, roughly, the same as the ratio of the revolving component of flux to the pulsating component, can be determined

for any particular speed from the calculated values of I_{3t} and I_{3f}. This nature of the squirrel cage current is of interest, in view of the fact that metallic strips or wedges are placed in the narrow slits connecting the squirrel cage slots with those of the commutated winding. These metallic strips serve the purpose of improving commutation by furnishing to the coils undergoing commutation local secondary circuits which absorb the energy that might otherwise appear in the form of very slight sparks at the brushes. The question of commutation and the action of the squirrel cage and these metallic strips in improving commutation has been rather fully discussed in the preceding paper by Mr. Bergman.

Alternation of the leakage flux which threads these thin metal strips induces eddy currents in the strips, which has the effect of reducing the effective leakage reactance of the squirrel cage. The metal strips are therefore designed with sufficiently high resistance so that the eddy currents induced in them by the full-line frequency alternation of leakage flux at standstill will be so small as to be practically negligible. Otherwise, the effective leakage reactance of the squirrel cage

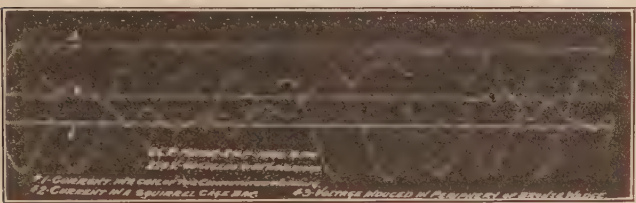


Fig. 10

would be appreciably reduced and the starting torque per ampere of starting current would be decreased.

When the motor is running at normal speed, the leakage flux threading the strips varies in the same manner as the squirrel cage current, *i. e.*, with a large slip frequency component and a small double frequency component. The effect of the slip frequency component in producing eddy currents in the strips will be entirely engligible on account of the very low frequency. The double frequency component can have only a very slight and practically negligible effect, on account of the small amplitude. The total effect of the metal strips on the operation of the motor is therefore quite negligible except for the improvement in commutation, and as is evidenced by the close agreement between the tested and calculated values shown in Fig. 4, it is perfectly legitimate to ignore the presence of the strips in calculating the performance characteristics of the motor, provided the strips are so designed as to properly take care of the standstill conditions.

In Fig. 10 are oscillograms showing the nature of the currents in the squirrel cage bars, the eddy currents in the metal strips, and the current in an individual coil of the commutated winding. In order to get an oscillogram showing the equivalent of the eddy currents in the wedges, an exploring coil was wound in the rotor with one side in the bottom of a commutated winding slot, and the other in the upper part of the corresponding squirrel cage slot. The wave shape of the voltage induced in this coil shows that the eddy currents in the metal strips consist largely of irregular high-frequency pulsations, which represent energy that is transferred during commutation from the commutated winding to the metal strips.

Acknowledgement

The writer wishes to acknowledge his indebtedness to S. R. Bergman and to P. L. Alger for helpful suggestions in connection with the development of the theory and the method of calculation.

Appendix

Let
$$X' = X_m + x_2$$
$$X'' = X_m + x_2 + x_3$$

Using these abbreviations, the complete expressions for the functions in equations (**12**) to (**18**) are:

$$F_1 = r_2\, r_3^2 - 2\, r_3\, x_3\, X'$$
$$F_2 = -\, r_2\, X''^2 - r_3\, X'^2$$
$$F_3 = 2\, r_2\, r_3\, X'' + r_3^2\, X'$$
$$F_4 = -\, x_3\, X'\, X''$$
$$F_5 = r_1\, F_1 - x_1\, F_3 - r_2\, r_3\, X_m\,(X_m + 2\, x_2 + 2\, x_3) - r_3^2\, x_2\, X_m - r_3^2\, X_m^2 \sin^2 A$$
$$F_6 = -\, 2\, r_3\, x_3\, X_m^2 \sin A \cos A$$
$$F_7 = r_1\, F_2 - x_1\, F_4 + x_2\, x_3\, X_m\, X'' + x_3^2\, X_m^2 \sin^2 A$$
$$F_8 = r_1\, F_3 + x_1\, F_1 - 2\, r_3\, x_2\, x_3\, X_m - 2\, r_3\, x_3\, X_m^2 \sin^2 A + r_2\, r_3^2\, X_m$$
$$F_9 = r_3^2\, X_m^2 \sin A \cos A$$
$$F_{10} = r_1\, F_4 + x_1\, F_2 - r_2\,(x_2 + x_3)\, X_m\, X'' - r_3\, x_2\, X_m\, X'$$
$$F_{11} = -\, x^2{}_3\, X_m^2 \sin A \cos A$$
$$G_1 = -\, 2\, r_3\, x_3$$
$$G_2 = -\, r_3^2 \tan A$$
$$G_3 = -\, r_3\, X'$$
$$G_4 = x_3\, X'' \tan A$$
$$G_5 = r_3^2$$
$$G_6 = -\, 2\, r_3\, x_3 \tan A$$
$$G_7 = -\, x_3\, X''$$
$$H_1 = -\, r_2\, r_3 \tan A$$
$$H_2 = -\, r_2\, X''$$
$$H_3 = -\, x_3\, X' \tan A$$
$$H_4 = r_2\, r_3$$
$$J_1 = H_4$$
$$J_2 = -\, [r_3\, X' + r_2\, X''] \tan A$$
$$J_3 = r_2\, r_3 \tan A$$
$$J_4 = H_3$$
$$M_1 = [2\, r_2\, r_3^3\, X' + 4\, r_3^2\, x_3^2\, X' + r_3^4\, X'] \sin A \cos A$$
$$M_2 = r_2\, r_3^2\, [-\, r_2\, r_3 + 2\, x_3\, X' \cos^2 A - r_3^2 \sin^2 A - 2\, x_3\, X'' \sin^2 A - 2\, x_3^2 \sin^2 A]$$
$$M_3 = r_3\, x_3\, X' \sin A \cos A\, [r_3\, X' - 2\, r_3\, x_3 + 2\, r_2\, X'']$$
$$M_4 = r_3\, [2\, r_2\, r_3\, x_3\, X'' \sin^2 A + r_2\, r_3\, X'^2\,(1 + \sin^2 A) + r_2^2\, X''^2 + 2\, x_3^2\, X'^2 \sin^2 A + r_3^2\, X'^2 \sin^2 A]$$
$$M_5 = x_3^3\, X'\, X'' \sin A \cos A$$
$$M_6 = -\, x_3^2 \sin^2 A\, [r_2\, X''^2 + r_3\, X'^2]$$

The first step in calculating the performance charac-

teristics of a squirrel cage repulsion motor from its design constants is to calculate the constants F_1 to F_{11} and M_1 to M_6 given above. Using the constants thus obtained, the calculation of current, power-factor input, torque, etc., can be carried out for all desired speeds simultaneously. Taking advantage of the fact that the constants to be calculated contain many terms and combinations of terms in common, and by using suitable calculation forms, the calculations can be completed in much less time than would be expected, judging from the lengths of the equations.

An analytical expression for the instantaneous value of the current in an individual conductor of the squirrel cage would undoubtedly be so complicated as to be entirely out of the question. If it is desired to determine the wave shape of this current for any particular speed, it can be readily determined from the calculated values of I_{3t} and I_{3f}. Referring to Fig. 11, the instan-

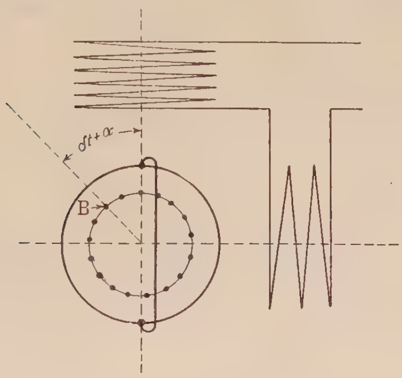


FIG. 11

taneous value of the current in the bar B is given by the equation

$$i_B = \sqrt{2}\,[\,|I_{3t}| \sin(\omega t + \theta_1) \sin(\sigma t + \alpha) + |I_{3f}| \sin(\omega t + \theta_2) \cos(\sigma t + \alpha)\,]$$

where $|I_{3t}|$ and $|I_{3f}|$ represent absolute values, θ_1 and θ_2 are the phase angles of I_{3t} and I_{3f} referred to the line voltage and α is the angular position of the bar when $t = o$. Transforming this equation into one involving functions of the sum and difference of two angles, we get the equation,

$$i_B = I_B' \sin[(\omega - \sigma)t + \beta_1] + I_B'' \sin[(\omega + \sigma)t + \beta_2]$$

or $i_B = I_B' \sin(s\,\omega\,t + \beta_1) + I_B'' \sin[(2 - s)\,\omega\,t + \beta_2]$ where I_B', the amplitude of the slip frequency component is given by the equation,

$$I_B' = \sqrt{\tfrac{1}{2}\,[|I_{3t}|^2 + |I_{3f}|^2 + 2\,|I_{3t}|\,|I_{3f}| \sin(\theta_2 - \theta_1)\,]}$$

and I_B'' the amplitude of the component whose frequency is $(2 - s) f$, is given by the equation,

$$I_B'' = \sqrt{\tfrac{1}{2}\,[I_{3t}^2| + |I_{3f}^2| - 2\,|I_{3t}|\,|I_{3f}| \sin(\theta_2 - \theta_1)\,]}$$

and β_1 and β_2 are constants.

CEMENT JOINTS VS. LEAD JOINTS

BY W. W. MONK
Shanghai Waterworks Company, Ltd.

In electric light power stations where there are large water intakes for cooling purposes, etc., it will be found that the cement joint is very suitable, reducing the cost of lead joints, etc.

Most of the Waterworks Engineers, who have experimented with all kinds of patented water joints, have always had some fault to find with the different patented joints.

Some little time ago I had occasion to cut out a small section of pipe which included a cement joint, and was made by me about 10 years ago. On examination it was found as good as on the day it was put in; although this pipe was laid only two and one-half feet under the surface of the road and had to contend with heavy traffic during its 10 years service under the earth.

In making the cement joint, the pipe is placed and spaced in the usual manner. A thin packing of the best dry spun yarn is used instead of oakum, as the spun yarn is free from oils and grease, which should be avoided. A Portland cement, confirming to the specifications advocated by the British or American Society for Testing Materials, is used. The dry cement is placed through a very fine sieve on to a piece of board 18 in. square. Silver sand is also placed through the fine sieve and mixed with this cement making a mixture of one and one, *i. e.*, the same quantity of cement with the same quantity of sand. After this has been done, it is moistened with just sufficient water so that when thoroughly mixed by hand it will be of a high consistency and when gripped tightly in the hand, it will hold the form of the hand. When dropped from the height of about 16 in. it will crumble.

In making the joint

1. Caulk the dry spun yarn into the back of the socket.

2. Start at the bottom of the socket and work towards the top, at the same time tapping the cement into place by hand with a caulking iron until the bell is about half full. It is then caulked with heavy blows until the cement is heavily packed to the back of the socket. The process is continued until the socket is packed full.

3. A small beading of neat cement in a plastic condition is then put around the whole of the joint using a small trowel.

4. As soon as the cement has become hard and set, backfilling of the excavated trench can then be gone on with, although it is always advisable to leave the joint holes open and test the pipe line before filling in.

The above joints were made on 8 in. and 12 in. mains, the working pressure of which is 40 to 50 lb. per square inch. The cost of the materials used works out one-third of the cost of ordinary lead joints.

Lightning Arresters

BY CHARLES E. BENNETT
Member, A. I. E. E.
Georgia Railway and Power Co., Atlanta, Ga.

SURGES and lightning potentials have been, to a great extent, dissipated over the overhead lines, and have caused innumerable interruptions on this part of the electrical system. It has recently become possible to keep the factor of insulation so good on transmission lines that disturbances are now more often reflected into the generating stations or substations, or their allied equipments.

In the opinion of the writer, protective devices must be installed more frequently than in former times for the reason that, as stated above, our lines are becoming better insulated. Furthermore, more substations of relatively small capacity, such as customer's substations, are now being installed directly on high and medium-voltage distribution systems.

The use of water in arresters originated in the simplest form of the old water resistance type used years ago

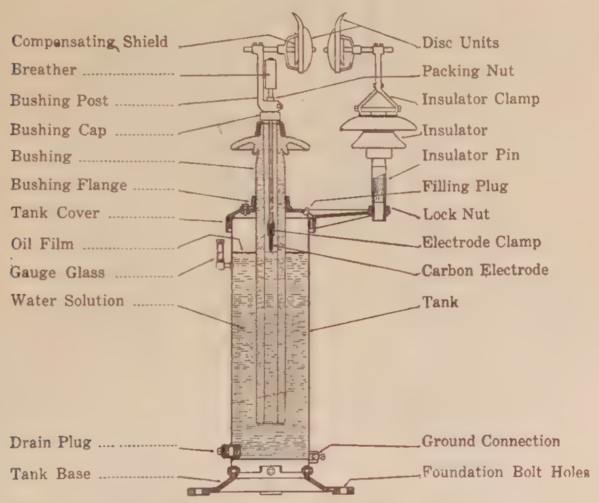


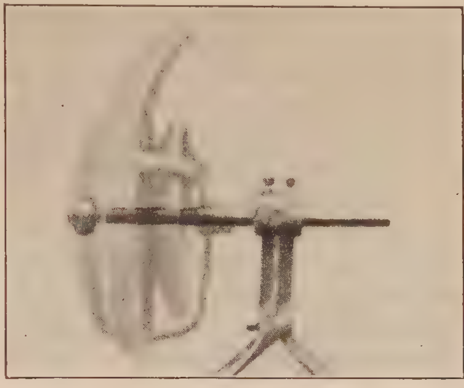
FIG. 1—TYPICAL CROSS SECTION OF SURGE ARRESTER

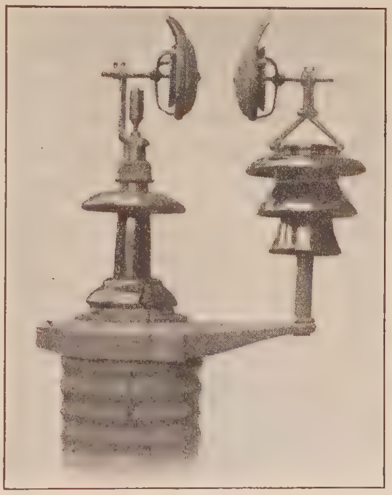
for d-c. railway systems. An electrode, immersed in a grounded tank of water, was connected directly to the power-house feeder through a switch, which was closed on the approach of a storm. This device appeared crude and cumbersome, but it was to some extent efficient if the operator did not forget to close the switch.

In Europe the use of water-jet arresters has been extensively adopted, whereby a jet of water from a grounded water pipe is squirted up against some metallic plates connected to the line. The size of the jet and its height depend on the voltage of the line, the purity of the water, etc.

The surge arrester described in this paper, is composed of two essential parts: the liquid resistance, and the high-speed gap, which are explained separately in the following paragraphs.

The liquid resistance is contained in a grounded metallic tank. A porcelain tube, open at its lower end, is partly immersed in the liquid; the upper end of the tube extends above the electrolyte and through the top, and above the tank. The electrolyte entering the bottom of the tube, comes to the same level as that in the tank surrounding the tube. Extending from the top of the tube and connected to one side of the gap,





FIGS. 2 AND 2A—THE COMPENSATED GAP

is a metallic conducting rod and carbon electrode, the end of which is in point contact with the electrolyte inside the tube. The metallic tank of the apparatus is connected to the ground and forms the ground electrode of the apparatus. The column of electrolyte inside the tube, in addition to its other more important functions, serves as a primary limiting resistance to ordinary line discharge through the arrester.

The line current having once crossed the speed gap, passes through the stem of the upper electrode and

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into the electrolyte at the contact between the carbon electrode and the electrolyte inside the tube. This rapidly causes the production of a heated vapor which produces pressure in the chamber above the electrolyte and causes the electrolyte to recede from its contact with the upper electrode, and to draw an arc between that electrode and the surface of the electrolyte. The arc is then attentuated within the tube of the interrupter and extinguished at the external air gap.

Liquid resistances, as used in this type of arrester, have the following advantages:

They can be made non-freezing, have low ohmic resistance, and be non-evaporating; together with large capacity for absorbing heat compared with all other types of resistance.

Carborundum resistances have the weakness of being too fragile, and often break under discharge. They have little or no capacity to absorb heat, and, therefore, often are ruptured due to gases internally released. However, liquid, when used in the arresters, has many advantageous qualities useful in absorbing transient waves, for example:

The liquid contained in a standard 1¾-in. tube, 31 in. long (1100 cu. cm.) will absorb approximately 368,000 watt-sec. in coming to a boiling point, requiring power applied at the rate of 3680 kw., to accomplish this in 1/10 sec. In order to raise the temperature from 20 deg. cent. to 100 deg. cent. and vaporize the entire contents of the tube would require further expenditure of 2,500,000 watt-sec. or 2500 kw-sec., or 0.7 kw-hr. This, if accomplished in 1/10 sec., neglecting losses in radiation, conduction, etc., would require application of power at the rate of 25,000 kw. In order to raise the liquid to the boiling

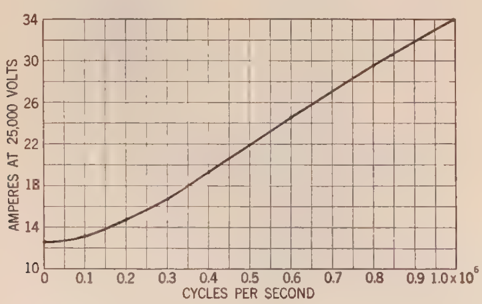


FIG. 3—DISCHARGE CURRENT SURGE ARRESTER

point and evaporate the entire contents in 1/10 sec. would, therefore, require nearly 29,000 kw. of applied power.

Another interesting characteristic of water is that it has a very high coefficient of penetrability. We have from Dr. Steinmetz's "Transient Electric Phenomena," the following data:

Material	Penetration in Cm. at		
	60 cycles	10,000 cycles	1,000,000 cycles
Copper	0.82	0.064	6.4×10^{-3}
Salt solution (Solution conc)	1.45×10^{3}	112	11.2
Pure river water	65×10^{3}	5030	503

It can be seen from the above that at the higher frequencies all the copper conductors take on an added resistance, but the water does not. Therefore, the resistance of water will remain constant at lightning frequency.

In designing the surge arrester, the resistance is so proportioned that it will not cause electro-dynamic surges during discharge, but will possess sufficient

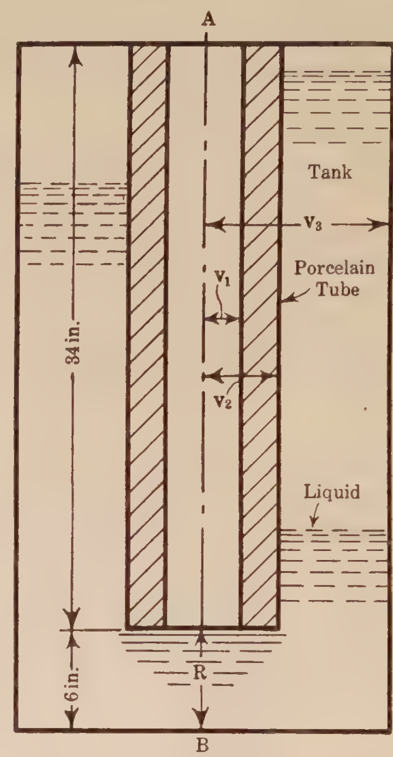


FIG. 4

$V_1 = 0.875$ in.
$V_2 = 1.625$ in.
$V_3 = 5.5$ in.
Porcelain $K = 8$
Resistance between $A - B \cong 2000$ ohms.

RESISTIVITY OF SOLUTION

$$\rho \frac{34}{24} + \rho \frac{6}{95} = 2000$$

$\therefore \rho \cong 140$ ohms — inch

i. e. 140 ohms between faces of a one-inch cube

RESISTANCE BETWEEN TUBE AND TANK

$$R_1 = \frac{140}{2\pi} \times 2.303 \log 5.5/1.625 \ \Omega/\text{inch}$$

$$= \frac{140 \times 2.303}{2\pi} \times .529 = 27.1 \ \Omega/\text{inch}$$

$$\therefore R = 27.1 \div 34 = 0.8 \text{ ohm}$$

$$R = \frac{140 \times 6}{95} = 8.85 \text{ ohms}$$

CAPACITY OF TUBE

$$C = \frac{38{,}800 \times 8 \times 34}{5280 \times 12 \log 1.625/0.875} \ \mu\mu f$$

$$= 620 \ \mu\mu f = 0.00062 \ \mu f$$

INDUCTANCE OF TUBE

$\cong 0.1 \ \mu h$ at high frequencies (neglect its effect)

conductivity to drain the line and prevent damage to adjacent apparatus when high frequency is impressed on the line.

In the salt solution used in the arrester, there is no screening effect within the range of lightning frequencies At a frequency of one million cycles the penetration is 11.2 centimeters; hence a diameter of water column of several inches would be subject to no inequality of current distribution, nor increase in resistance consequent. In any high-frequency conductor, the ohmic resistance is usually negligible compared to the effective resistance due to the unequal current distribution. This, it is seen, is not the case with this arrester, but will be true of any other path to ground that can be devised other than water or some electrolyte similar to the salt water solution.

Many types of lightning arresters must have an arc gap in series with the device. A most desirable arc gap would be one that could be set at slightly above line potential, under all weather conditions, so that it would arc over easily and quickly and tend to drain from the line surges of small amplitude. The gap would then, with the assistance of the arrester, shunt abnormal potentials soon enough in the propagation of the wave to protect the apparatus and their insulating materials from abnormal stress.

If the circuits of the commercial frequencies were the only ones we had to contend with, it would be comparatively easy to design a spark gap, which, as long as it was kept dry, would function and protect insulation and apparatus, but since most lightning impulses or oscillatory disturbances are induced upon commercial frequencies or superimposed on the normal wave, the problem is a much more difficult one to solve, and the design more complicated in its characteristics.

The earlier forms of lightning arresters consisted of the use of horn gaps ahead of the arrester equipment. By some exhaustive experimental research, there was discovered the now well-known impulse ratio, which denotes the ratio of impulse breakdown voltage of the gap to a continuously applied breakdown voltage; and as a result, the shape of the electrode nearest suited to all conditions was found at that time to be that of the sphere.

However, it must be noted that the sphere gap is very much influenced by the presence of rain or other moisture, so much so that it will break down at a much lower potential than the predetermined spacing for dry conditions. When, therefore, it is desired to use an unprotected sphere gap, it can be seen that if it is set for dry weather spacing, rain or moisture will cause the gap to spark-over at considerably less applied potential. This precludes the satisfactory use of the sphere gap for outside installation, as it has to be given a wet spacing which requires nearly double line voltage to break down when dry. The covering of such gaps does not entirely eliminate trouble.

The new type of *compensated impulse gap* shown in the illustration, has nearly the same arc-over voltage when wet as when dry, and it has a lower arc-over voltage for impulse potentials than for normal frequencies. These are the advantages that make it unusual and most valuable for service. It may be given a setting for dry conditions under normal voltage at 60 cycles without danger of discharging at lower potentials in wet weather. It has been found in service that many high-frequency disturbances with steep wave fronts will dissipate themselves through the gap and arrester even before reaching line voltage value.

Each unit of the new type of gap consists of a brass

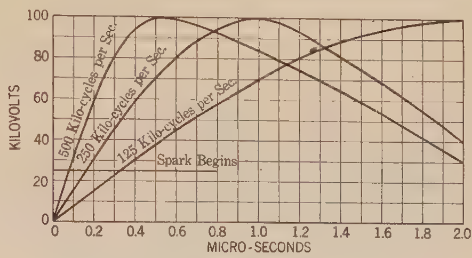


Fig. 5—Impulse Traveling Waves

pointed terminal about an inch and one-quarter in diameter, mounted in the center of a convex disc of especially designed, highly-refractory porous porcelain which remains unaffected by the arc heat repeatedly applied. On the outer rim of this porcelain disc, there is a metallic ring with a projection on the top to form an arcing horn. Back of the porous porcelain disc is an adjustable shield, which can be moved closer to the porcelain or away from it to increase the sensitiveness of action of the device to impulse potentials. The entire gap is substantially supported from a 11/16 in. shaft, and the arcing ring on the outside of the porcelain

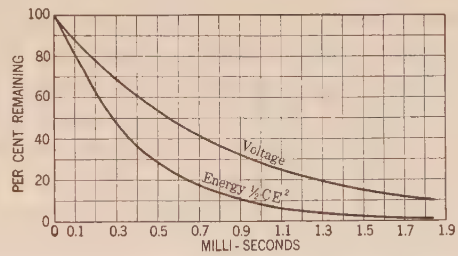


Fig. 6—Discharge of Condenser Through Resistance

disk is supported through the spokes of the spider indicated in the drawing.

The functioning of this device under wet and dry conditions and impulse voltages is as follows:

It is well known that at ordinary commercial frequencies, spheres of large diameter have a higher arc-over voltage for a given spacing than spheres with small diameter. In this new type gap, when the porcelain is dry, the discharge area is equal to only that of the brass point in the center, but when it is wet, the porcelain acts as a conductor instead of an insulator and thus increases the terminal area. In other words,

the gap compensates for weather conditions by this change in electrical characteristics, by atuomatically replacing the small spheres or points with a large spherical area of terminal with no change in spacing, due to the absorption of moisture by the porcelain disk, the porous porcelain, although a good insulator when dry becoming a conductor when wet. These porcelain disks dry out quickly after rain, due to the drying effect of the electrostatic field always present at the gap when in service. While the moisture in the air manifestly decreases the arc-over voltage value in the usual horn or sphere gap, it increases the arc-over value of these gaps somewhat as the larger disk of wet porcelain is equivalent to, and takes on the characteristics of, a large sphere. Thus, gaps, as shown in the curves, have a somewhat higher break-down value when wet than when dry, a most desirable function.

In the design of the compensated impulse gap, it was desired to secure a gap that would have an impulse breakdown voltage less than that of sphere gaps under dry weather conditions, as it is at this period, on the

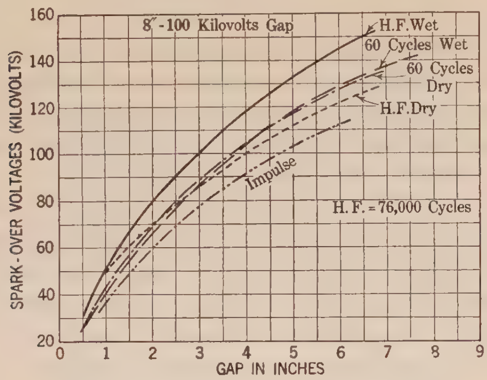


Fig. 7—Compensated Impulse Gap

approach of a storm when the gaps are dry, that the greatest stresses are produced.

It is desirable that a perfect gap should function upon voltage ripples due to switching surges, induced lightning potentials, static or impulses of any sort during dry weather conditions.

As indicated in the curves shown, the dry weather impulse potential curve of the compensated gap is considerably lower than the 60-cycle continuously-applied breakdown voltage, but can be adjusted in relative value. There are two adjustments on the gap, which control the sensitiveness to impulse voltage. This is accomplished by revolving the adjusting metallic plates. When these plates are moved closer to the porcelain disk, the sphere-gap characteristics under impulse potentials are obtained, and the gap is less sensitive to impulse or high-frequency disturbance.

When the disk is close to the porcelain, the total flux between the gap has been largely increased because of the greater capacity brought about by bringing the two comparatively large metallic plates closer toward the center of the gap; due to increased flux density a greater impulse potential is required for spark-over. In other words, the dielectric between the electrodes, which includes the porcelain and air, is more uniformly stressed; and therefore requires, as stated above, more potential to over-stress or break down the gap.

By revolving the metallic plates away from the rear of the porcelain disk, we obtain a slightly more sensitive setting to impulse potentials, since when the metallic shields are moved back from the porcelain disk, the electrostatic capacity over the gap has been lessened.

The moving of the adjusting plates forward and backward from the porous porcelain disk when wet,

Fig. 8—G-84-110,000-Volt Arrester, Atlanta, Ga.

does not influence the high frequency of 60-cycle setting; the breakdown then following very nearly the characteristics of a large sphere.

The successful gap and lightning arrester must have little or no time lag in order to protect apparatus from harm when subjected to impulse potentials.

An impulse voltage reflected upon electrical apparatus must have time and energy in order to rupture insulation. The destructive discharges through a dielectric requires not merely a sufficiently high voltage but a definite amount of energy. The destructive discharge does not occur instantly with its application, but a finite, though usually small, time elapses after

the application of the voltage before the discharge occurs. During this time interval, energy must be supplied to the dielectric. As a result, therefore, the perfect gap and arrester combination should function at the beginning of this energy period in order to absorb and dissipate disruptive energy and prevent its entering the apparatus to be protected.

If this combination has a perceptible time lag, the impulse voltage will be applied to the dielectric for a part of the time at a given energy rate, and over-stressing of the dielectric of the apparatus is sure to occur. Continual subjection to over-stressing will cause injury and ultimate breakdown of such apparatus.

The compensated impulse gap appears not to change its normal frequency breakdown value when wet or dry, and can, therefore, be given the close dry setting slightly above normal line potential with the assurance that it will not discharge at less than line potential when wet. It does not need protection by covering, and is set up in free air, thereby providing the necessary ventilation for quickly cooling the parts for the removal of conducting gases.

It will discharge impulse or high-frequency disturbances, giving them the least chance to rise to destructive values. Its impulse value and its normal frequency value are capable of calibration independently, the gap presents a fixed value to all discharges even under the heaviest rainfall usually experienced, and needs no weather protection for this function.

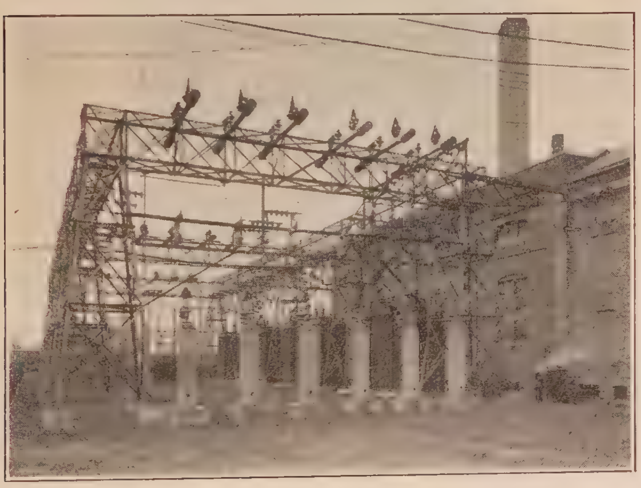


Fig. 9—D H-34 S Installation at Kenova, W. Va.

An interesting feature of the surge arrester, which has been observed on a number of occasions, is that when the approaching storm builds up a field nearby a substation, this arrester spills over quite frequently; and in some cases operates for three or four seconds continuously, indicating that the device is draining a superimposed potential. It is true that the line current follows, but as the dynamic current taken through the arrester is perceptibly small, this loss is negligible; and as this continuous discharge can easily take place in the arrester for several hours, evaporating but a very small amount of water, or only slightly over-heating it, it can be seen that the device tenaciously sticks to its job.

The question of discharge rate has been one of the principal objections to liquid type arresters. It has been an outstanding assumption that an arrester is not an arrester unless it has a capacity to discharge heavy currents of impulse characteristics from line to earth. Most of the American type of arresters appear to have been designed with this idea in mind.

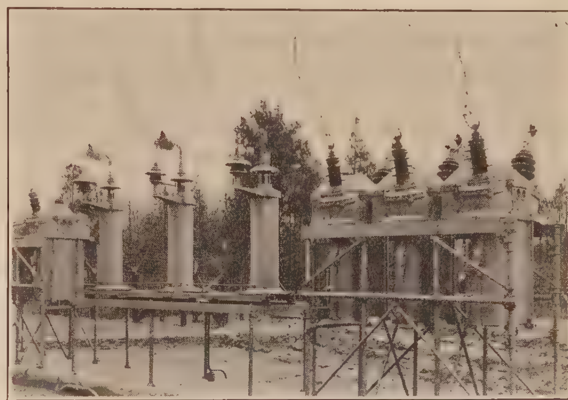


Fig. 10—D-24 Arrester at East Point, Ga.

The surge arrester, from the following calculations, shows that the device has a somewhat different discharge rate than would naturally be supposed, due to a capacity effect of the submersion of the tube in the electrolyte, and its general design. A curve is shown, giving the calculated discharge rate of an arrester discharging at 25,000 volts under different frequencies. From this curve can be noted that the discharge rate from the arrester varies from 12 to 34 amperes through the range of frequencies from 60 to one million cycles. In other words, the steeper the wave front, the higher the discharge rate. Of course, if the potential over-shoots 25,000 volts, or point of discharge, at a given setting or gap, the discharge rate will increase in proportion to the voltage increase, so that if the potential over-shoots to three times 25,000 volts or 75,000 volts, the discharge rate would be three times that indicated on the curve.

Fig. 5 shows the operation of the surge arrester under different steepnesses of wave front such as 125, 250 and 500 kilocycles, and you will note that this arrester should function at approximately 25 per cent over line voltage. If an arrester does not function until 200 per cent line voltage, it can readily be seen that there is considerable time lost in getting into action. As a result, it is necessary to have a high discharge rate in order to make up for time already lost.

Fig. 6 shows the time required to discharge a 30-mile 20,000-volt line charged up to a potential five times its working potential, or 100,000 volts through a

a 2000-ohm resistance. You can readily see that the time to bring the line potential back from abnormal to normal potential is in the neighborhood of 0.2 milliseconds.

A line of this character with 48-in. spacing, 4/0 conductors, would be

Resistance of conductor	= 0.277 ohms per wire mile—25 deg. cent. 60 cycles
Capacitance " "	= 0.0172 microfarad per wire mile
Inductance " "	= 0.00177 henry per wire mile
Surge impedance	= 321 ohms

If the line voltage is suddenly raised to 100,000 volts the surge current is 312 amperes.

Frequency of oscillations. Energy passing from magnetic to dielectric field, or vice versa $= \frac{1}{2\pi} \sqrt{LC} =$ 965 cycles per sec.

Energy stored in a 0.4 micro-farad condenser at 100,000 volts = 2 kw. sec.

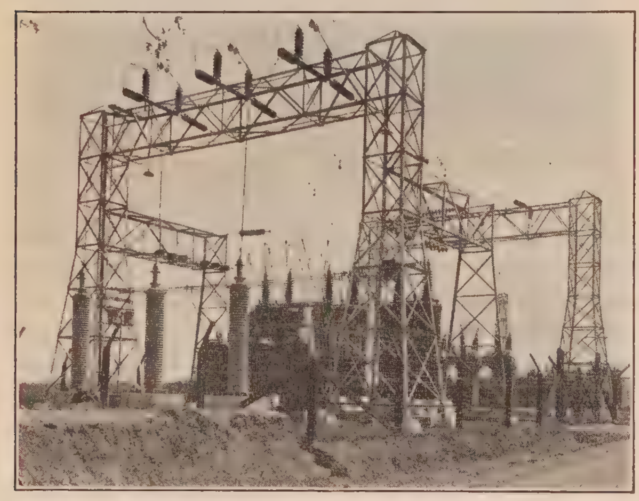


Fig. 11—G-84-110,000-Volt Installation at Cornelia, Ga.

Assuming a wave front of say 500 $K\ C$ and at a point where the arrester operates, the discharge rate would be approximately 22 amperes. However, should the raise in potential still persist, or the over-shooting effect be pronounced, then the discharge rate at a point near 100 kv. would be in the neighborhood of approximately 88 amperes. The time required, therefore, to drain the line from 25,000 volts, as shown in curve No. 6, would be in the order of 70 micro-seconds, so, therefore, it can be seen that although the discharge rate may appear to be low in the beginning, it rapidly increases with frequency and voltage. This apparent increase in discharge rate probably accounts for the successful operation of the device in a great many installations, as probably the average surge on a line is in the order of 100 amperes.

The question of the arc interruption in the tube was given considerable study, and a great many tests were made with oscillograph.

It was found that under maximum conditions, such as short-circuiting the gap, the interruption in the tube never took more than one-half cycle. However, this does not occur when the speed gap is in the series with the tube. Successive tests, made at approximately 700,000 cycles, showed that the path through the tube was continuous even when a super-potential was imposed on the 60-cycle potential.

In concluding this paper, the writer wishes to make it clear for the Institute that the theories advanced are the result of observations and tests covering a considerable period and may not be a true analysis. The question of discharge has been freely advanced as the only solution, but we appear to get protection

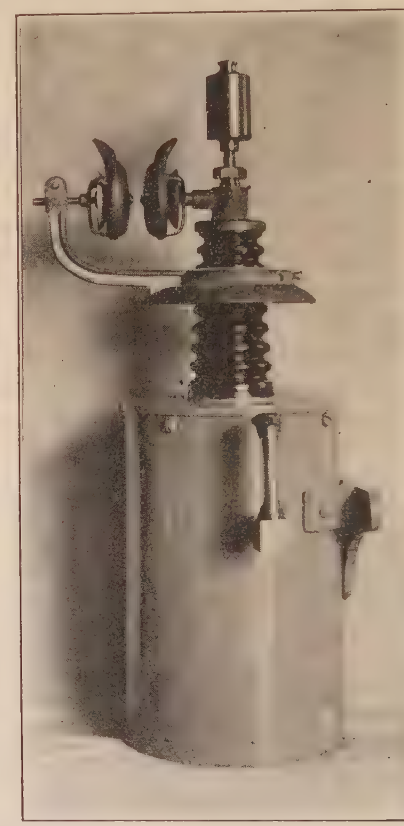


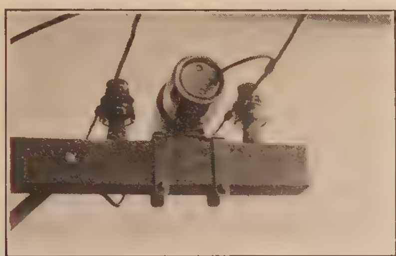
Fig. 12—D-7 Arrester, Signal Type, Pennsylvania Railroad, 4000-Volt Block Signal System

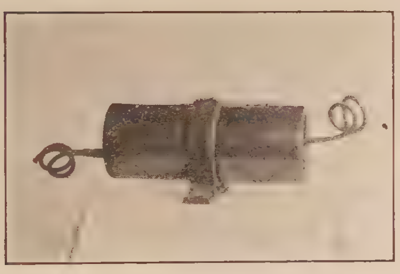
with a lower degree of discharge rate in these arresters than has ever been thought possible in any other type, as has been shown by active and successful protective service on several thousand installations on transmission lines all over the country.

The writer has always previously accepted the theory of the high-discharge arrester as the only type of effective protective device; however, after carrying on numerous tests and field observations of the operation of the surge arrester during storms and surges, there is in the writer's mind a question as to whether or not we do not get equally as efficient protection with less discharge rate.

It is difficult to ascertain by experiment or test what the time lag of apparatus of this nature may be. As the writer sees it, the breaking down of one air gap in a circuit, especially where the gap has the characteristic of arcing over quickly on either super-potential or super-frequency, and where the rest of the apparatus provides a continuous path, the combination must have less time lag than where it is necessary to break down many air gaps in series, or to break down many insulating films which have to be punctured before the surge can discharge.

Any arrester, to have a small time lag, must have as little inductance in the circuit as possible; and this we have endeavored to secure in the design described. Therefore, is not a small time lag plus slightly longer time to drain the potential, equally as effective as a perceptible time lag, plus a high discharge rate?





FIGS. 13 AND 14—600-2300-VOLT ARRESTER

Below are noted the curves, tables and calculations which indicate the probable discharge rate of the surge arrester, as well as illustrations of typical installations.

SUMMARY

Type *D*-7	7	sets operating at	4 kv.	2 at 2.3 kv.
" *D*-20	3	" " "	11 kv.	1 at 2.3 kv.
" *D*-24	32	" " "	19 kv.	
" *D*-34	25	" " "	38 kv.	
" *C*-24	17	" " "	19 kv.	
" *G*-84	7	" " "	110 kv.	1 at 66 kv.

91 sets in operation — 4 sets in operation
4 " " "
95 " " "

The total number of these arresters in operation on the Georgia Railway & Power Company's System (as of data from Testing Department) is 95. There are other arresters not listed.

TABLE I

Frequency	ω	Z_0	θ	$\tanh\theta$	I_A
10^6	$2\pi\times10^6$	715	2.79	1.0275\	34.0
$.8\times10^6$	$.8\times2\pi\times10^6$	802	2.49	1.056 "	29.5
$.6\times10^6$	$.6\times2\pi\times10^6$	925	2.16	1.10 "	24.5
$.4\times10^6$	$.4\times2\pi\times10^6$	1132	1.76	1.14 "	19.35
$.3\times10^6$	$.3\times2\pi\times10^6$	1312	1.53	1.136 "	16.75
$.2\times10^6$	$.2\times2\pi\times10^6$	1600	1.25	1.065 "	14.70
$.15\times10^6$	$.15\times2\pi\times10^6$	1850	1.08	0.985 "	13.72
$.1\times10^6$	$.1\times2\pi\times10^6$	2260	0.88	0.845 "	13.10
$.09\times10^6$	$.09\times2\pi\times10^6$	2385	0.835	0.810 "	12.90
$.08\times10^6$	$.08\times2\pi\times10^6$	2530	0.788	0.768 "	12.85
$.06\times10^6$	$.06\times2\pi\times10^6$	2920	0.682	0.670 "	12.80
$.00\times10^6$					12.50

$$I_A = \frac{E_A}{Z_o \operatorname{Tanh}\theta} \text{ amperes.}$$

$$I_A = \frac{25{,}000}{715\,\overline{\backslash 45^\circ}\times 1.0275\,\overline{\backslash 1.34^\circ}} \cong 34\ \underline{/46^\circ} \text{ amperes}$$

$$Z_o = \sqrt{\frac{r}{j\,c\,w}} = \sqrt{\frac{2000\times10^6}{0.00062\times2\,\pi\times10^6}}$$

$$= \sqrt{\frac{3.23\times10^6}{2\,\pi}} = \sqrt{513{,}000} = 715\,\overline{\backslash 45^\circ} \text{ ohms}$$

$$\theta = \sqrt{r\times j\,c\,w} = \sqrt{\frac{j\,2000\times0.00062\times2\,\pi\times10^6}{10^6}}$$

$$= 2.79\ \underline{/45^\circ} \text{ hyps.}$$

$$\therefore\quad \operatorname{Tanh}\theta = 1.0275\,\overline{\backslash 1.34^\circ} \text{ numeric.}$$

RADIO COMMUNICATION IN MINES

Development of a line-radio or "wired-wireless" system, by which trolley wires, mine tracks, compressed air and water piping, cables and similar "carriers" are utilized for voice-transmission purposes, promises the solution of the difficult problem of establishing methods of communication between underground mine workers and the surface, which would be reasonably sure to withstand the severe disturbances occasioned by mine explosions.

In tests recently conducted in a coal mine 400 feet deep, no difficulty was experienced on the surface in receiving radio messages from a transmitting set mounted upon a mine locomotive as long as the apparatus was in the vicinity of metallic carriers. The Bureau of Mines experiments indicate that the transmitting range of a radio set in the average coal mine is only a few hundred feet when no conductors are present, but may be several thousand feet when operating in proximity to metallic carriers. The bureau found that breaks in the metallic conductors do not completely stop communication as in the case of a break in the lines connecting the ordinary mine telephones. Fire, falls of rock and roof, explosions, mine flooding and other mine disasters which might cause one or more breaks will not completely destroy the conductors, and communication between underground workings and the surface could probably be established.

An Electrical Frequency Analyzer

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Associate, A. I. E. E.

and

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***Review of the Subject.**—An apparatus has been developed by means of which it is possible to obtain a permanent record of the frequency and magnitude of each component of a complex alternating current. The device has two frequency ranges: 20 to 1250 cycles and 80 to 5000 cycles. The power required does not in general exceed 500 microwatts, and the time necessary for making a record is about 5 minutes. An attachment is provided by which, in the same length of time, two simultaneous analyses can be made if desired.*

In principle, the process consists in introducing the complex voltage to be analyzed into a selective network, the essential feature of which is a sharply tuned circuit whose frequency of tuning is controlled by varying the capacitance in small steps with a pneumatic apparatus similar to that in a player piano. A maximum of response of the circuit occurs at each frequency of tuning which coincides with a component of the complex wave. An automatic device records this response at each frequency of tuning, making a photographic record from which the frequency and magnitude of each component of the complex current may be obtained. For convenience of operation, an automatic control apparatus is provided, so that it is only necessary to connect the complex source or sources to be analyzed and press the starting button.

The application of the analyzer in communication problems is shown by a few illustrative uses. A record of the output of a carbon transmitter button driven at an excessive amplitude shows harmonics of the driving frequency and of half the driving frequency. With a condenser transmitter the analyzer can be used to analyze sustained sounds in the air and the application of this method to tones of a few low-pitched organ pipes shows large differences in relative harmonic content. Analyses of the electrical input and acoustic output of a common type of loud speaker give an idea of the amount of distortion.

The use of the analyzer in power problems is shown by records taken on a transformer at load and at no-load, and similar records on a d-c. generator. The no-load transformer record shows the amount of third and fifth harmonic in the exciting current with the secondary open. The d-c. generator records show various parasitic frequencies from 30 cycles to over 4000 cycles, and a consideration of the records leads to the probable causes of these parasitic frequencies

Introduction

THE electrical frequency analyzer described in this paper consists of a variable tuned circuit into which the complex alternating voltage to be analyzed is introduced, and an automatic recording apparatus to register its response as the frequency of tuning is changed.

The first recorded use of a tuned circuit as an analyzer was by Pupin in 1894.[1] He analyzed power waves by measuring the response of circuits tuned to each of the harmonic frequencies. It has been the practise for a number of years to determine the frequency characteristics of currents and voltages on power circuits and noise on telephone lines by means of a variable resonant circuit which includes a telephone receiver for listening. During the recent war a rapid automatic method was developed for varying the tuning of a resonant circuit in connection with the analysis of sounds radiated by submarines. The analyzer described in this paper is in principle the same as this apparatus but includes such improvements as were found by experience to be desirable.

Principles of Operation of the Analyzer

Fig. 1 is a schematic diagram of the essential elements of the analyzer circuit. The complex current to be analyzed enters at the input terminals from which it passes to an input network and to the variable tuned circuit. The tuned circuit consists of a variable condenser of capacitance C and a coil whose inductance is L and resistance R. The value of the capacitance C is varied in small steps by means of automatic apparatus. The inductance L consists of four identical windings on a toroidal core which, by means of a switch, may be thrown in series or in parallel, thereby changing the value of the inductance in the ratio of 16 to 1. With the same range of capacitance values this change in inductance gives the two frequency ranges, 20-1250 cycles and 80-5000 cycles. By means of the trans-

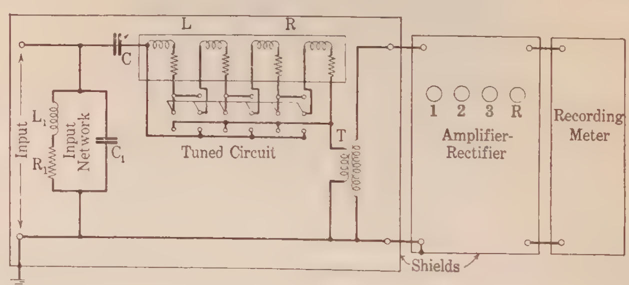

FIG. 1—SCHEMATIC ANALYZER CIRCUIT

former T the response of this circuit is applied to a vacuum tube amplifier-rectifier and registered by means of the recording meter. The use of an amplifier reduces the input power required by the analyzer to a value in general not over 500 microwatts. The recording meter makes a photographic record of the analysis.

The current fed into the analyzer traverses two paths; the input network and the tuned circuit. The impedance of the tuned circuit is low at its resonant frequency, but the impedance of the input network is relatively constant with frequency on account of the damping effect of resistance R_1. Any component of the complex

1. Resonance Analysis of Alternating and Polyphase Currents, TRANS. A. I. E. E., Vol. XI, p. 523, 1894.

Abridgment of a paper presented at the Midwinter Convention of the A. I. E. E., Philadelphia, February 4-8, 1924. Complete copies available to members on request.

current having the frequency to which the tuned circuit is resonant flows, therefore, largely through the tuned circuit, and is recorded by the analyzer. This circuit arrangement analyzes a complex wave by virtue of the selective shunting of current by the tuned circuit from the input network. As the resonant frequency of the tuned circuit is changed, successive components of the complex wave are recorded. The analyzer will, therefore, not indicate the phase of the components, but has the advantage that the component frequencies

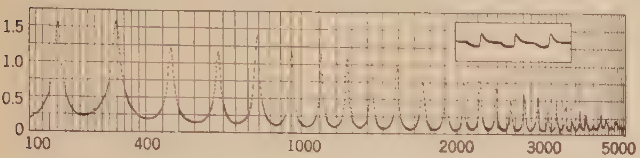

Fig. 2—Record of 160 Cycle Buzzer Output

need not be even multiples of the lowest frequency as is the case with graphical analyzers. The impedance of the source of the complex current is in practise maintained high in value at all frequencies compared to that of the input network, so that the input wave-shape is independent of the changes in the impedance of the analyzer due to the varying of capacitance C. The input network is a damped parallel resonant circuit designed empirically to give the analyzer an approximately constant calibration for the 80-5000 cycle range, so that records for this range are direct-reading.

In Fig. 2 is shown the photographic record of analysis of the current from a buzzer which vibrates with a frequency slightly under 160 cycles per second and gives an irregularly shaped wave which is shown in the inserted oscillogram. In taking this record, the windings of the tuning inductance were in parallel so as to give the frequency range 80-5000 cycles. The record consists of a number of peaks, each signifying the presence of one frequency component. The frequency and approximate r. m. s. current in milliamperes for any component may be obtained by reading the coordinates of the highest point of the peak representing this component. It will be seen that each multiple of the fundamental frequency of the buzzer is present. The root-square sum of all components shows that 4.7 milliamperes was the effective value of the complex current fed into the analyzer.

The frequency scale is gradually contracted as the upper end of the record is approached. The apparatus is designed to do this on account of the fact that the sharpness of tuning of the resonant circuit decreases with frequency.

The analyzer is equipped with a device which permits the making of simultaneous analyses of two complex waves. It may be used to show two analyses on the same record for comparison, or simply to save time. The device operates by connecting alternately to the analyzer the two complex waves in such a way that the record for each wave is traced by points representing alternate tuning condenser settings. The employment of this device will therefore reduce errors in comparing two sources which vary with time, one depending on the other.

Description

The mechanism of the analyzer is so designed that to take a record it is only necessary, after starting the amplifier and connecting to a 110-volt power source, to attach the leads from the source or sources to be analyzed and press a starting button. The completed record is then automatically delivered in about five minutes, after which the apparatus returns to the starting condition ready to repeat the operation. This automatic operation is accomplished by the use of a player piano roll, appropriately perforated to operate the various parts of the analyzer in the proper sequence. The development of the pneumatic apparatus was carried out with a view to making use of as many standard piano player parts as possible. The entire apparatus is mounted on a two-deck table about 2½ feet by 6 by 3 feet high.

Applications

The application of the analyzer has so far been principally to problems in the communication field such as the analysis of the performance at audio frequencies of vacuum tube and mechanical oscillators and amplifiers, analysis of complex telephone waves and speech sounds, and the effect on a complex wave of transmission through electrical and acoustic apparatus. In the power field many applications are obvious, such as for example, quantitative comparison as to frequency content of the voltage and current supplied to and delivered by transformers, voltage and magnetic flux studies in generators and motors, commutation, and the effect of wave-shapes in power line problems and control apparatus. To show the variety of these

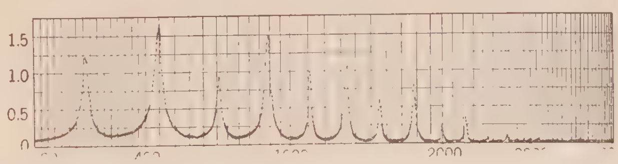

Fig. 8—Output of Carbon Button Driven at an Excessive Amplitude

problems in which the analyzer is a useful means of investigation, several illustrative records have been made and will be discussed. These records were taken in each case to illustrate the use of the analyzer and are not parts of investigations to which they are related.

One of the uses of the analyzer has been in the study of the performance of microphone buttons. Fig. 8 illustrates the character of the distortion in a button when driven at an excessive amplitude. The button was mounted so that its movable electrode could be

driven at a single frequency by a very heavy reed at its natural frequency, so that the motion was very nearly sinusoidal. The frequency of the motion was a little less than 450 cycles corresponding to the second peak on the record. The amplitude of motion was about 0.001 cm. or 0.0004 in., which is, of course, much greater than normally obtains in a transmitter. The circuit consisted simply of the button and a battery in series with the analyzer so that the record is an analysis of the current fluctuations in the button. The record shows two series of frequencies generated by the button; a primary series having for its fundamental the driving frequency, 450 cycles, and a subsidiary series, having for its fundamental half the driving frequency, or 225 cycles. The even harmonic components of the subsidiary series coincide, of course, with the frequencies of the primary series. The primary series can be accounted for by the fact that with such large amplitudes the changes in resistance are not a linear function of the amplitude of motion. The subsidiary series is due to the non-symmetrical effect of the inertia of the carbon grains in vibration, the motion being so violent that some of the grains are thrown free from their contacts. For small amplitudes such as those ordinarily encountered in a transmitter, a record would show only 450 cycles, the other frequencies occurring in negligible amount: for intermediate amplitudes the primary series only would occur.

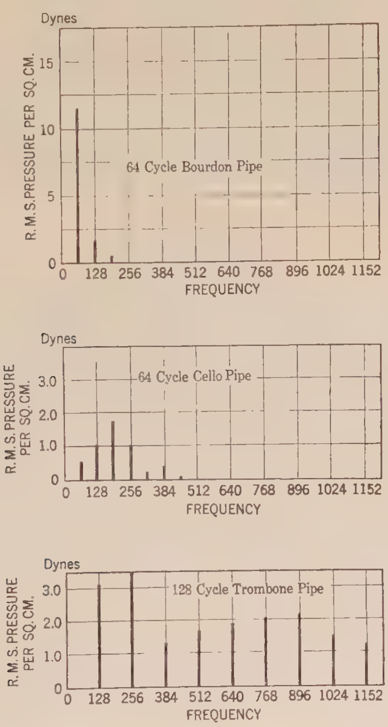

Fig. 11—Analysis of Organ Pipe Tones

The analyzer can be used to obtain in absolute units the intensities of the components of a sustained sound in the air by connecting it to the output of the amplifier used with a condenser transmitter,[2] and making a simple computation involving the calibrations of the transmitter and amplifier. This method has been used in the study of the frequency characteristics of vowel sounds and tones of musical instruments. Fig. 11 shows the analyses of three low-frequency organ pipes. These are plots of r. m. s. pressure change in the sound wave, each vertical line corresponding, of course, to a peak on the original record. The upper chart shows the almost pure tone given by a 64-cycle bourdon pipe. In the case of the cello pipe, also having a fundamental of 64 cycles, the third harmonic is more prominent than the fundamental or second harmonic. The third chart is for a 128-cycle trombone pipe which was found to be rich in harmonics. The pressure in the single components of the cello and trombone pipes is less than in the case of the bourdon pipe, and a larger scale of ordinates is therefore used.

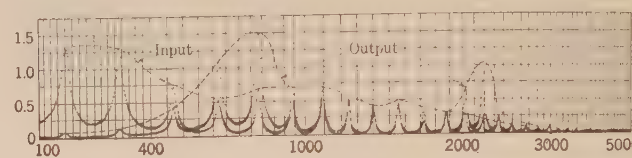

Fig. 13—Records of Electrical Input and Acoustic Output of a Common Type of Loud Speaking Receiver

To illustrate the use of the attachment which permits the making of two simultaneous analyses, a few double records will be presented. Fig. 13 is a double record showing analyses of the buzzer current input to a common type of loud speaking receiver and the acoustic output as picked up by a condenser transmitter placed in front of the loud speaker at a distance of about 15 inches. The analysis of the input current to the loud speaker is shown by the comparatively continuously decreasing series of peaks. The acoustic output is represented by the series having maxima in the neighborhood of 800 cycles and 2200 cycles. This record, however, cannot be taken as an adequate analysis of this loud speaker because of probable reverberation effects in the room.

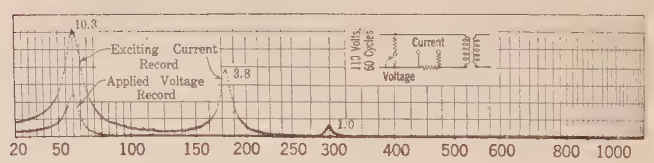

Fig. 14—Record Taken on Transformer at No Load

The analyzer has thus far not been used in the study of power problems. A few illustrative records have

2. "A Condenser Transmitter as a Uniformly Sensitive Instrument for the Absolute Measurement of Sound Intensity." E. C. Wente, *Physical Review*, July 1917.

"The Sensitivity and Precision of the Electrostatic Transmitter for Measuring Sound Intensities." E. C. Wente, *Physical Review*, May 1922.

been taken, however, on transformers and generators; these will be shown and discussed as suggestive of the use of this method of attack in such problems.

Fig. 14 is a double record over the 20-1250 frequency range, of applied voltage and exciting current of a small 110-volt, 60-cycle transformer operating at normal voltage and frequency under the no-load condition. The presence of the well-known third and fifth harmonics in the exciting current is clearly shown. Because of the rise in the calibration curve of the analyzer at the low end of the lower frequency range, a scale of ordinates is not shown on this record; instead, the values of the analyzer current at each frequency are noted. The circuit used in making this record is shown in the figure. A computation of the components of the exciting current from the record and the constants of the circuit shows that at 60 cycles the current was 175 milliamperes, at 180 cycles 65 milliamperes, and at 300 cycles 17 milliamperes. The root square sum of these gives the total exciting current as 187 milliamperes.

The operation of this transformer under full load is shown in Fig. 15 where, as before, the primary voltage and current are analyzed. The transformer load

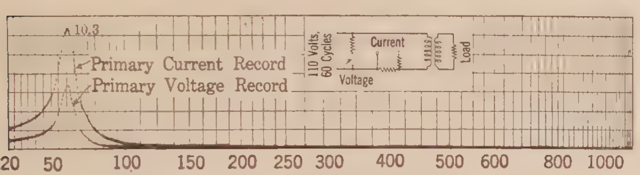

Fig. 15—Record Taken on Transformer Under Load

consisted of a pure resistance. It will be noted that the third and fifth harmonics have become very small compared with the fundamental. From the analyzer current noted on the record and the resistances used in connecting the analyzer, the primary current was found to be 310 milliamperes.

Problems relating to commutation may also be conveniently studied qualitatively and quantitatively by means of the analyzer. The value of an apparatus which will measure the extent and distribution of parasitic frequencies is obvious; moreover such data taken for a few operating conditions will probably reveal the sources of the parasitic frequencies. Information has been obtained on a small machine direct-driven by a ½-h. p. 60-cycle single-phase motor. The generator tested was a 125-volt two-pole shunt wound, 1800-rev. per min. machine, rated at ¼ kw. The armature winding was laid in 19 slots and connected to a 38-bar commutator, 2.75 in. in diameter. There were two 3/8-in. square carbon brushes.

Records obtained from this machine when operating under no-load and half-load conditions are shown in Figs. 16 and 17, respectively. The corresponding speeds are approximately 1800 and 1750 rev. per min. In order to show what frequencies the machine gives out over the entire frequency range, 20 to 5000 cycles, each figure is made up of two parts: a portion of a 20-1250 record, and a complete record over the range 80-5000 cycles. On each figure is drawn the circuit connecting the d-c. generator to the analyzer. A large condenser is inserted to prevent the passage of heavy direct current through the analyzer.

The consideration of these records leads to the conclusion that there are at least three independent major causes of alternating voltage operating in this d-c. machine. The fundamental frequencies due to these causes are 30, 60 and 570 cycles. It will be noted that the 30-cycle peak occurs only on the no-load record under which condition the average speed is practically

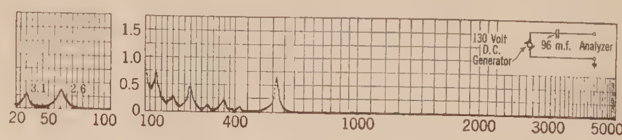

Fig. 16—Record Taken on D. C. Generator at No Load

30 revolutions per second. Sixty cycles and a series of its harmonic overtones are seen to be present under both conditions of load. Under load the 60 cycles is augmented whereas its harmonics are reduced. No harmonic overtones of 30 cycles except such as might coincide with the harmonics of 60 cycles are found in either case. This indicates the existence of independent causes of the 30 and 60 cycle frequencies, also that the 30-cycle cause produces an almost sinusoidal voltage, and that the 60-cycle cause under no-load produces an irregular wave which becomes smoother as the machine is loaded.

The no-load record, Fig. 16, shows 570 cycles with

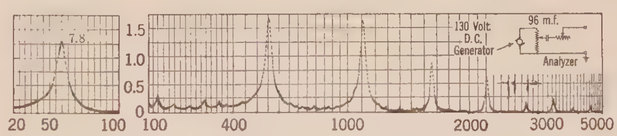

Fig. 17—Record Taken on D. C. Generator Under Load

no harmonics, while the load record, Fig. 17, shows this frequency with a complete series of harmonics. This indicates that at no load the cause of 570 cycles feeds a relatively smooth wave to the line while under load this cause feeds an irregular wave to the line. The frequency really falls to 550 cycles under load on account of the reduction in armature speed. The fact that 1100 cycles is about as strong as the fundamental and that its harmonics are stronger than alternate frequencies which are overtones of 550 only, suggests the likelihood of a fourth cause of alternating voltage, having a frequency of 1100 cycles. Small irregularities at frequencies other than those already mentioned occur in the record. These are more prominent under load than

at no-load and indicate the presence of small, more or less irregular pulses, which increase with load.

All of the above frequencies may be accounted for by a consideration of the construction and operating condition of the machine. The generator was driven by a single-phase, four-pole, 60-cycle motor which may give rise to torque fluctuations once per revolution, or 30 times per second. Under no load this may produce considerable corresponding fluctuations in speed while under load conditions the generator acts as a damper, eliminating these oscillations.

The 60-cycle peak is due to some cause which produces two cycles of voltage fluctuation for each revolution of the armature. The records show that for this particular machine in its present condition (new) at normal speed the 60-cycle voltage developed increases considerably with load, indicating strongly that the cause is largely influenced by an $I R$ drop somewhere in the machine. The most likely causes, therefore, appear to be commutator eccentricity, irregular spacing of the segments, or high mica.

The peak at 570 cycles may be accounted for by cyclic variation of flux entering the armature core as the teeth pass the pole faces. At no-load the speed is approximately 1800 rev. per min. The number of teeth being 19, it is obvious that there will be 570 fluxtuations of air-gap reluctance per second. Under no-load conditions the record shows a comparatively pure wave form for this cause. This is to be expected because of the comparatively uniform distribution of flux under the pole faces at no load. As the machine is loaded, however, the field is distorted and shifted giving rise to an irregular wave form of voltage which is responsible for at least a part of the large harmonic content shown by the load record.

The 1100-cycle peak which is present only under the load condition, may be due to the cyclic variation of voltage produced by the commutator bars leaving the brushes. Inasmuch as the speed is roughly about 29 revolutions per second the frequency with which bars leave brushes is about 1100 cycles. This frequency is present under the load condition only, thus indicating that it is due to an $I R$ drop at the brush contacts or to an e. m. f. developed in the short-circuited coil with the brush off the magnetic neutral.

The very small irregularities shown particularly between peaks above 550 cycles on the load record are probably due to slight chattering of the brushes.

It is of interest to note that the so-called frequency of commutation does not appear in either of the records. For this machine this frequency at no load is approximately 346 cycles per second.

From these records it is possible to determine the r. m. s. value of the alternating voltage at any frequency of interest. This is computed from a knowledge of the circuit constants and analyzer impedance. We thus obtain for the load condition values of 1.1 volts at 60 cycles and 0.8 volts at 550 cycles.

In general the records taken by means of the analyzer on this commutating machine, confirm quantitatively the well known fact that such machines may give rise to frequencies in the audible range. Considerations of the records has indicated causes for these frequencies which may be divided into two classes: First, those controlled by design, and second, those controlled by the physical condition of the machine at any particular time. It is also interesting to note that the driving motor may produce an appreciable effect, particularly under the no-load condition.

Summary

In the above paper there has been given a short statement of the theory and construction of an automatic, recording, electrical frequency analyzer, together with illustrations showing its use in various fields.

This apparatus has been found very useful in the laboratory in the investigation of many different types of problems chiefly because of the speed with which records can be made and analyses obtained without computation.

In conclusion the authors wish to express their appreciation to Mr. C. E. Lane and Mr. C. E. Dean, of the Western Electric Company, Inc., for their assistance in the building of this machine and in the preparation of this paper.

SOME METHODS OF TESTING RADIO RECEIVING SETS

Technologic Paper, No. 256, on "Methods of Testing Radio Receiving Sets" is ready for distribution by the Superintendent of Documents at 10 cents per copy. The paper describes methods of measuring the electrical characteristics of a radio receiving set and formulates statements of features which may be learned by an inspection of the electrical and mechanical design of a set. This work was undertaken at the request of the Bureau of Agricultural Economics of the Department of Agriculture, representatives of radio manufacturing companies, testing laboratories, and other organizations. In developing the test methods described it has been the Bureau's aim to provide means for determining to what extent a receiving set embodies the following characteristics:

1. Sufficient sensitivity to produce audible or loud sounds when tuned to receive from stations which may be located at a considerable distance.
2. Selectivity, or the ability to respond to signals of a given frequency without responding to signals of slightly different frequency.
3. Convenience of operation and simplicity of manipulation, so that persons not highly trained nor conversant with the details of the circuits used may still be able to operate the receiving set satisfactorily.
4. Effectiveness in covering the range of frequencies used by the transmitting stations which it is desired to receive.
5. Substantial construction, which will insure the set remaining in serviceable condition in spite of rough handling received during shipment and use.

Temperature Rise of Stationary Electrical Apparatus as Influenced by Radiation, Convection and Altitude

BY V. M. MONTSINGER
Member, A. I. E. E.
and
W. H. COONEY
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Review of the Subject.—*Part I of the paper takes up first the division of losses by radiation and convection from tall vertical planes. It is shown that the loss by convection from tall planes can be expressed by the formula*

$$W_c = 0.0014\, A\, \theta^{5/4}$$

in which W_c is the watts, A the square inches of surface and θ the temperature rise in degrees centigrade.

It is then shown that the division of losses from a black plane is, for temperature rises up to 100 deg. cent., approximately 45 per cent convection and 55 per cent radiation. Based upon this division, a simple formula is given for determining the ratio of losses for an irregular surface where the greater part of the loss is by convection.

The effect of various colors on the temperature rise of transformers having both plain and corrugated tanks is discussed.

In Part II it is shown that altitude does not affect radiation. The general average of the results obtained by various investigators shows that convection varies as the square root of the air density. Based on this, it is shown that for a constant loss by convection the temperature rise increases about 4.6 per cent for each 1000 meters increase in altitude. For transformers where a part of the loss is by radiation (unaffected by air density) the effect is reduced by the ratio of the convection loss to the total loss. Also the effect on the winding rise over the ambient is further reduced by the fact that the winding rise over the oil is not affected by altitude. The effect of the copper loss, however, is to increase the effect of altitude because the resistance is increased by temperature.

Based upon the above facts it is shown that the temperature rise and rating of the two main classes of oil-immersed self-cooled transformers are affected by altitude as follows:

	Per cent increase in Copper Rise per 1000 Meters Increase in Altitude	*Per cent decrease in Kv-a. per 1000 Meters Increase in Altitude*
Self-cooled transformers.........		
(a) with plain tanks..........	*1.75*	*1.35*
(b) with corrugated, tubular and radiator tanks.............	*3.0*	*2.3*

Introduction

While the main purpose of this paper (which is a companion paper of the one by Doherty and Carter[1]) is to give the effect of altitude on the heating of stationary apparatus cooled by radiation and free convection, it is very essential to first determine how the cooling is effected. For instance, we must know the relative parts radiation and convection play in cooling the different shapes of surfaces used, especially for self-cooled oil-immersed transformers, because (1) the ratio of losses by these two modes of cooling varies, depending on the shape and color of the surface, etc., and (2) these two modes of cooling are not affected alike by altitude. The paper, therefore, falls into two logical divisions, namely:—

1. The temperature rise of various shaped surfaces as influenced by radiation and free convection for a given altitude and
2. Effect of altitude on temperature rise of apparatus having various shapes of surfaces.

One of the writers gave a paper[2] before the Institute in June 1916 in which was shown by tests how the heating of three transformer tanks, each having different shapes of surfaces, were affected by altitude.

Since that time considerable experimental work has been carried on to establish, first, the correct formula for free convection; and second, a method for calculating the cooling capacity of various shapes of surfaces under a constant air pressure where both radiation and convection enter into the cooling, especially where convection plays such an important part as it does for tank surfaces having different widths and depths of corrugations. So far as literature shows, no method has ever been given by which to predetermine with any degree of accuracy the thermal efficiency of corrugations.

Part I gives the results of tests made on a large plate to determine the formula for free convection. Also the results of tests and a discussion are given on the effect of different colored cases on the temperature rise of transformers in the shade and sunshine.

Part II deals with the effect of altitude on the temperature rise of transformers having different shapes of tank surfaces, of rheostats, bus bars, reactors, etc.

Part I

Temperature Rise of Various Shaped Surfaces as Influenced by Radiation and Convection for a Given Altitude

A. Radiation. The accepted law of radiation, known as the Stefan-Boltzman law, is of the form:

$$W_r/A = K\, e\, (T_2^4 - T_1^4) \qquad (1)$$

where W_r/A is the watts dissipated per unit surface, K is a constant, e is the emissivity factor depending on color, being 1.0 for a lamp black surface, and T_2 and T_1 are the hot body and ambient temperatures in absolute degrees centigrade respectively. If expressed

1. Effect of Altitude on Temperature Rise by R. E. Doherty and E. S. Carter.

2. Effect of Barometric Pressure on Temperature Rise of Self-Cooled Stationary Induction Apparatus" by V. M. Montsinger.

Presented at the Annual Convention of the A. I. E. E., Edgewater Beach, Chicago, Ill., June 23-27 1924.

in watts per square inch, according to the latest accepted value, $K = 3.68 \times 10^{-11}$.

Fig. 1 shows the radiation of heat in watts per square inch plotted against temperature rises over various ambient temperatures.

B. Convection. Several years ago, Dr. Irving Langmuir developed and published[3] the film theory which assumes that heat loss by convection is dissipated by first passing through an adhering film of gas, where most of the temperature drop occurs, and then is carried away by convection air currents.

While the film theory formula checked tests made at high temperatures, it did not check tests made on tall planes at low temperatures. According to the formula, the loss was approximately proportional to the temperature rise up to 100 deg. cent., whereas numerous tests made on various kinds of tank surfaces showed that convection loss varied as the temperature rise raised to the 5/4 power. This was pointed out in the paper presented in 1916.

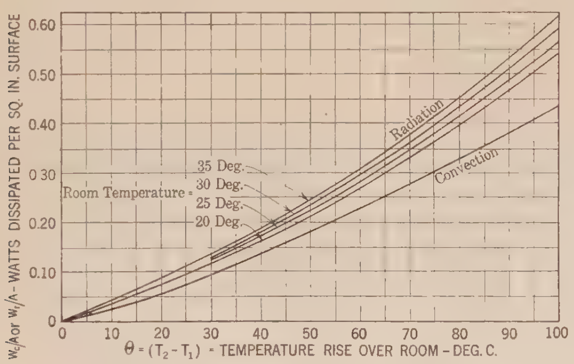

FIG. 1—RADIATION OF HEAT FROM BLACK BODY BY STEFAN-BOLZMAN LAW
$W_r/A = K e (T_2^4 - T_1^4)$, WHERE $K = 3.68 = 10^{-11}$, T_2 AND T_1 ARE ABSOLUTE TEMPERATURES, DEG. CENT. ASSUME $e = 0.9$ AND CONVECTION OF HEAT BY EQUATION: $W_c/A = 0.0014\ \theta^{1.25}$, WHERE θ = TEMP. RISE—DEG. CENT.

Based on the film theory and "Method of Dimensions" Rice[4] developed and presented at the annual A. I. E. E. Convention in June 1923 a free convection formula of a form such that when the convection watts W_c are plotted against temperature rise Δt up to 100 deg. cent. the resulting equation is:

$$W_c = K A \Delta t^{1.06} \qquad (2)$$

in which K is a constant, A is the area.

But from 100 to 500 deg. cent. rise, the exponent in Rice's formula is approximately 1.25.

Since the temperature rises of most electrical apparatus do not exceed 100 deg. cent. it appeared to be of sufficient importance to make accurate laboratory tests to determine (1) the correct value of the exponent and (2) the constant for vertical surfaces representing tall tanks. As Rice's formula was known by the writers well in advance of its publication, there was sufficient time to complete these tests and give, in a condensed form, the results in a discussion of his paper. In this discussion it was shown that free convection from tall planes can be expressed for temperature rises up to 300 deg. cent. by the formula:

$$W_c = K A \theta^{5/4} \qquad (3)$$

in which W_c = convection watts,
K = 0.0014 for a plane 31.5″ tall
A = area in sq. in.
θ = temperature rise in degrees centigrade

Fig. 1, also shows values of W_c/A plotted against θ.

Further details as to how the formula was derived are given later under "Experimental Observations on Vertical Plate."

Recently Rice[5] has, by introducing the temperature coefficient of density of the air in his previous formula, developed one for large vertical plane surfaces in air which agrees in substance with equation (3). It is of the form:

$$W_c = 0.0078 A (1/H)^{1/4} P^{1/2} (1/T_{avg})^{.123} \Delta t^{5/4} \qquad (4)$$

in which W_c = Loss in watts
A = Area of surface
H = Height of plane
P = Absolute air pressure in atmospheres
T_{avg} = Average of hot body and ambient absolute temperatures degree K.
Δt = Temperature rise of hot body in deg. cent.

For a rise of approximately 50 deg. cent. in a 25 deg. cent. room and for a plane 31.5 in. (80 cm.) tall, equation (4) reduces to

$$W_c = 0.001285 A P^{1/2} \Delta t^{5/4} \qquad (5)$$

Rice has, therefore, cleared up the disagreement between the *rate* of *loss* with *temperature rise* which has existed between the film theory formula and results of tests made at low temperature differences. We now have for the first time a true conception of the physics of convection for both high and low temperatures differences.

C—Radiation and Convection from Various Shaped Surfaces

(*a*) *Large Vertical Planes.* Table I shows the calculated division of losses from a plain black surface, using the convection formula $W_c = 0.0014 A \theta^{1.25}$ and the radiation formula $W_r = 3.68 \times 10^{-11} A e (T_2^4 - T_1^4)$, in which $e = 0.9$ and $T_1 = 298$ deg. K (25 deg. cent.)

For practical purposes we can say that for vertical planes the losses from, say, 20 to 100 deg. cent. rise, are 55 per cent radiation and 45 per cent convection.

(*b*) *Large Vertical Corrugated Surfaces.* One of the most universal methods of increasing the area of a trans-

3. PROC. A. I. E. E. Feb. 1913.

4. Free Convection of Heat in Gases and Liquids by C. W. Rice. Presented at A. I. E. E. Annual Convention in Swampscott, Mass., June 1923.

5. Free Convection of Heat in Gases and Liquids by C. W. Rice. Presented at A. I. E. E. Midwinter Convention in Philadelphia, February, 1924.

TABLE I
DIVISION OF LOSSES FROM LARGE PLAIN, BLACK VERTICAL SURFACE IN 25 DEG. CENT. ROOM AT SEA LEVEL

Temperature Rise Deg. Cent.	Watts per sq. in. by:		Per cent of Total Loss by:	
	Radiation	Convection	Radiation	Convection
10	0.039	0.025	61	39
20	0.0765	0.057	57.5	42.5
30	0.121	0.095	56	44
40	0.171	0.137	55.5	44.5
50	0.224	0.182	55	45
60	0.28	0.230	55	45
70	0.344	0.279	55	45
80	0.415	0.329	56	44
90	0.492	0.382	56	44
100	0.57	0.439	56.5	43.5

former tank without increasing its floor space is to corrugate the surface. Since there are so many possible variations in the pitch depth and height of corrugations, it is very essential to be able to predetermine the cooling capacity, *i. e.* the loss per unit of area of the developed surface for various temperature rises.

(*c*) *Surface of Corrugations Effective for Radiation and Convection Radiation:* Referring to Fig. 2 the surface A represents the envelope of a single corrugation

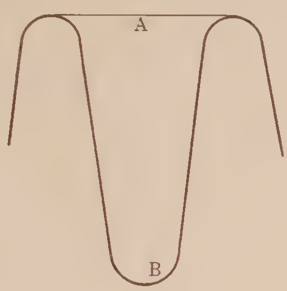

FIG. 2—SHOWING SURFACES OF A CORRUGATION EFFECTIVE FOR RADIATION AND CONVECTION

B. It is obvious that both sides of A will radiate equal amounts of heat. Now B will radiate the same amount of heat to A as A radiates to B; otherwise one body would gain heat at the expense of the other. Since A is the envelope area of B and, furthermore, since A and B have equal radiating capacities, the true radiating surface of a corrugation (or any irregular surface) is its outer envelope. (A mathematical proof of this which is rather long, is given by Rud. Kuchler in *Electrotechnische Zeitschrift*, Jan. 1923, Vol. 44).

Convection. The surface effective for convections is of course the total developed area, providing the air currents are allowed to circulate freely over the entire surface.

(*d*) *Total Cooling Capacity of Plain and Corrugated Surfaces*

(*1*) *Actual Losses:* The actual losses for any given maximum oil rise of either a plain or corrugated tank are difficult of accurate predetermination for the following reasons: (1) There are certain losses from the bottom and cover whose temperature rises are seldom accurately known; (2) the vertical tank gradient must be known; and (3) there exists a certain temperature drop from the oil to the tank, which drop must be known. However, in practise it is just as important and very convenient to be able to make comparisons of the heating of tanks having different shapes of surface with other tanks having similar vertical gradients. For instance, if we know what a plain tank will do for any given oil rise, it is convenient to know what some other tank with a corrugated surface will do for the same oil rise.

(*2*) *Relative Losses:* For any given top oil rise (providing the vertical gradients of the tank are similar) the ratio of the loss from the average shape of corrugation used in practise to the loss from a plain tank can therefore be expressed by the following equation:

$$L = \frac{55\,E\,e \times 45\,D}{100\,D} \tag{6}$$

in which L = ratio of total loss per unit of developed area to loss per unit of plain area, having the same temperature rise of the oil.

E = Outside envelope area.

e = Emissivity factor = 1.00 for ordinary black paint in this case.[6]

D = Developed area of surface.

There are, of course, limitations as to depth and width of the air space in the corrugation for which equation (**6**) holds. Experience has shown that it holds for a ratio of depth divided by width of approximately 4. However, as this ratio increases, it would be expected that the air circulation would become more and more restricted until the loss by convection was materially reduced. For instance, if the width of air space in a corrugation 6 in. depth was only 1/4 in., there is no question but that the air would be so restricted that the convection loss would be reduced enormously.

If the entire surface of a tank consists of similar corrugations we can let E equal the pitch, and D the developed length of a single corrugation and by substituting these values in equation (**6**) determine L. For instance if the pitch is 2 in. and the developed length is 6.6 in., the value of

$$L = \frac{55 \times 2 \times 1 + 45 \times 6.6}{100 \times 6.6} = 0.62$$

In other words one sq. in. of the corrugated area will dissipate 0.62 as much loss as one sq. in. of a plain area.

Now, since this tank has 6.6 in. of surface to each 2 in. of envelope, it has 3.3 times the total area of a plain tank of the same outside diameter. Therefore, the total loss dissipated by this corrugated tank will be 3.3 × 0.62 = 2.04 times that of the plain tank.

If equation (**6**) is expressed in terms of total loss L_1 per unit of envelope area instead of loss per unit of developed area (L), the equation reduces to

$$L_1 = L\,D/E$$

$$= \frac{55\,E\,e + 45\,D}{100\,E} \tag{7}$$

6. See Table II for values of e for Various Colors.

Effect of Height. Carefully made tests have shown that the effect of height is very small, the loss being only about 3 per cent more for a corrugated surface 36 in. in height than one 72 in. in height. In fact, experience has shown that the effect of height is so small that for practical purposes it can be neglected for all heights greater than about 2 or 3 ft.

D. *Effect of Color on Temperature Rise.* Table II gives the emissivity factors for various colors of paints often used on transformer tanks. These values were obtained from tests made on a plate 20 in. by 20 in. in a vertical position.

TABLE II
EFFECT OF COLOR ON EMISSIVITY

Color of Paint	Emissivity Compared with Black Surface (e = 0.9)
Black	1.00
Dark Green	0.97
Dull Red	0.91
" Grey	0.81
White	0.76
Copper (busbars)	0.65
Aluminum	0.62

The effect of color on radiation raises the question of how the temperature rise of a transformer is affected by various colors of paint when in the shade, or how it is affected by absorption of heat when exposed to the rays of the sun.

Since the division of losses from a plain black tank is approximately 55 per cent radiation and 45 per cent convection, the effect of other colors on the temperature rise may be easily calculated for any shape of surface in the shade. Table III shows this for a plain surface.

TABLE III
EFFECT OF COLOR ON TEMPERATURE RISE OF PLAIN TANKS

Color of Paint	Surface Rise in per cent of that for Black Surface
Black	100
Dark Green	101
Dull Red	104
" Grey	110
White	117
Aluminum	120

TABLE IV
EFFECT OF COLOR ON TEMPERATURE RISE OF TANKS HAVING APPROXIMATELY 75 PER CENT OF LOSS BY CONVECTION AND 25 PER CENT BY RADIATION

Color of Paint	Percentage Rise
Black	100
Dark Green	100.8
Dull Red	101.5
" Gray	104
White	105.8
Aluminum	109

It is thus apparent that a tank with an irregular surface is not appreciably affected by color.

In Sunshine

(*a*) *Plain Tank.* A plain tank will probably be affected the most. The results of tests made by Messrs. Moore and Moulton[7] of the San Joaquin Light and Power Corporation to determine the effect on the temperature rise of both black and gray plain tanks in the sunshine, are summarized by them as follows:

"The number of successive days during which tests were made and the consistency of the results leave little doubt as to the accuracy of the full load tests. The fact that a gray paint will not reduce the oil temperature more than 3 or 4 deg. fahr. or 1 or 2 deg. cent. during the extremely hot weather encountered in the San Joaquin Valley seems established. This was a disappointment in view of the seemingly prevalent belief that a much larger reduction for gray paint would be found."

It is apparent that the increased temperature, due to the lighter color (and reduced radiation) is approximately counteracted by the reduced absorption of heat from the rays of the sun.

(*b*) *Tanks with Irregular Surfaces.* Since heat absorbed by radiation is a function of the envelope surface only, there is every reason to believe that a tank of irregular shape will not be affected as much by the sun's rays, for a given color, as a plain tank.

It should be understood, of course, that the temperature rise will be greater in the sunshine than in the shade, regardless of color of tanks, the difference depending on several factors, such as direction of the sun's rays, the area of the tank exposed to the sun, and the intensity of the rays. Unfortunately, no reliable data appears to be available on this point.

E. *Experimental Observations on Vertical Plate.* The plate was of cast iron, (Figs. 3 and 4) 31.5 in. (80 cm.) high, 13.1 in. (33.3 cm.) wide, by 1 1/16 in. (2.7 cm.) in thickness, and had imbedded in it sheath wire units of equal resistance about 2 in. apart. This produced a uniform temperature over the whole area, including both sides, and eliminated the necessity of making appreciable stray losses corrections which would have been necessary if one side of the plate had been blanketed, as is sometimes done in investigations of this kind. In some of the tests the terminals and

TABLE V
LAMP BLACK SURFACE

W_t/A = total watts per square inch.
W_r/A = watts per sq. in. radiation (calculated)
W_c/A = $W_t/A - W_r/A$ = watts per sq. in. convection.
Area dissipating heat = 917.4 sq. in.

Test No.	Ambient		Average Temp Rise Over Ambient	W_t/A	W_r/A (e = 0.9)	W_c/A
	Air	Wall				
1	30	29	12.6	0.08095	0.04948	0.03147
2	32.7	31.4	22.5	0.1508	0.0954	0.0554
3	25.6	23.6	29.6	0.2145	0.1206	0.0939
4	28.5	27.8	38.7	0.3075	0.1705	0.137
5	31	30	51.5	0.4358	0.2465	0.1893
6	29.7	29	60.9	0.5450	0.3006	0.2444
7	29.7	28.4	72.1	0.6562	0.3735	0.2827

7. Effects of Various Colored Cases on Oil Temperatures of Distribution Transformers by L. J. Moore and J. H. Moulton in *Journal of Electricity and Western Industry*, June 1923.

TABLE VI

NICKEL PLATED SURFACE

Area Dissipating Heat = 931.2 square in. e = .07

Test No.	Ambient Air	Average Temp. Rise Over Ambient	W_t/A	W_r/A (e = .07)	W_c/A
8	23.2	13.7	0.03921	0.00394	0.0353
9	28.5	15.4	0.04779	0.00468	0.0431
10	30	21	0.06892	0.00669	0.06223
11	29.5	33.6	0.113	0.0113	0.1017
12	33.5	50.1	0.192	0.01898	0.173
13	28.2	64.2	0.2637	0.02476	0.2389
14	26.3	80.3	0.3561	0.03289	0.3232
15	23.8	91.6	0.4349	0.03867	0.3962
16	25.0	93.8	0.4349	0.04048	0.3944
17	27.0	101.8	0.4877	0.04635	0.4413
18	24.3	110.1	0.5647	0.05095	0.5137
19	25.6	118.6	0.6142	0.05749	0.5567
20	25.2	127.2	0.6828	0.06492	0.6179
21	28.3	143.5	0.7965	0.07975	0.7167
22	22.6	152.5	0.8635	0.08425	0.7792
23	28.2	60.8	0.2427	0.02294	0.2198
24	25.3	31.3	0.1141	0.00998	0.1041
25	24.8	60.1	0.2465	0.02194	0.2246
26	24.7	42.7	0.1602	0.01438	0.1458
27	28.7	309.8	2.615	0.3388	2.2762
28	30.7	241.3	1.699	0.2055	1.4935
29	26.2	178.8	1.043	0.1140	0.929
30	28.5	242	1.7615	0.2035	1.558

TABLE VII

PARTLY OXIDIZED SURFACE

Area Dissipating Heat = 836.5 sq. in.
Emissivity Factor e = 0.52

Test No.	Ambient Air	Ambient Wall	Average Temp. Rice °C Over Ambient	W_t/A	W_r/A (e = .52)	W_c/A
31	34	36.1	279.5	3.653	2.096	1.557
32	33.6	35.5	250.4	3.046	1.676	1.370
33	33.5	34.8	193.5	1.983	1.027	0.956
34	33	34.5	214	2.507	1.23	1.277
35	33.8	35.0	227.4	2.609	1.393	1.216
36	34.8	36.8	263.4	3.343	1.863	1.48
37	33.3	34.4	199.2	2.132	1.078	1.054
38	32.7	33.7	170.8	1.741	0.821	0.920
39	31.2	31.5	145.8	1.418	0.621	0.797
40	33.1	33.4	118.3	0.9865	0.4534	0.5331
41	32.6	32.6	69.4	0.5347	0.2116	0.3231
42	32.2	32.1	55.6	0.3569	0.1592	0.1977
43	31	31.1	55	0.3537	0.1549	0.2024
44	31.2	31.4	38.9	0.2363	0.1014	0.1349
45	31.2	31.5	29.8	0.1766	0.07435	0.10225
46	31.2	31.5	20.3	0.1126	0.04845	0.06415
47	31.3	31.6	14.4	0.07534	0.03364	0.0417
48	31.3	32.3	206.6	2.272	1.132	1.14
49	32.1	32.5	149.8	1.383	0.6545	0.7285
50	31.8	32.0	102.5	0.83	0.362	0.468
51	31	31.0	79	0.5908	0.2487	0.3421
52	32.7	32.6	47	0.2944	0.1292	0.1652
53	32.7	32.5	25.6	0.1474	0.06372	0.08368
54	32.5	32.3	14.5	0.07628	0.03422	0.04206
55	31.5	31.4	67.5	0.4693	0.202	0.2673

edges of the plate were blanketed. This accounts for the slight variation in the areas given in Tables V, VI, and VII.

The plate was suspended in a vertical position in the air in an open room having a constant temperature. Fifteen thermocouples were soldered in holes in the surface on one side and five on the other side of the plate, the five being used merely as a check to see if both sides were at the same temperature. The plate temperature was taken as the average of all thermo-couples. Direct current was used to supply the loss. All readings of volts and amperes and thermocouples were taken with a potentiometer. For convection, the air was used as the ambient. For radiation, the temperature of the walls of the room about 10 ft. distant was used for the ambient, although the air and wall temperatures were usually the same.

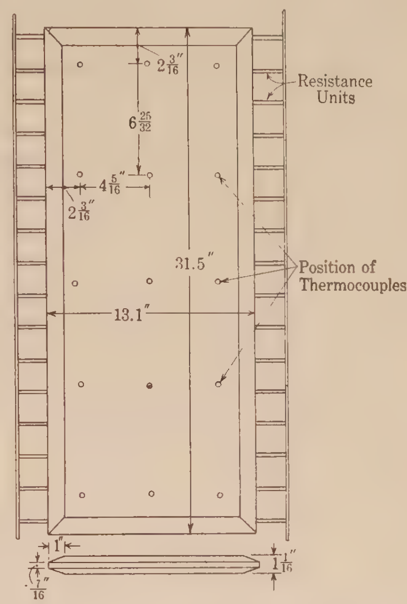

Fig. 3—Dimensions of Vertical Plate Used to Determine Convection Formula

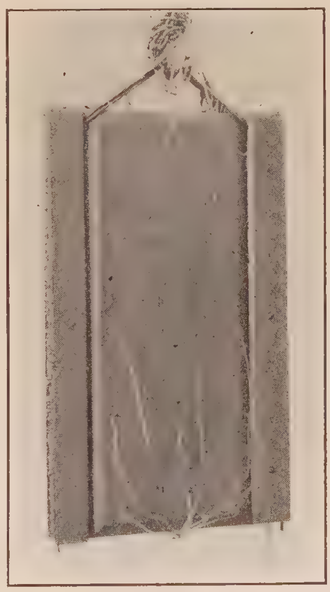

Fig. 4—Front View of Plate Used to Determine Convection Formula Blanketing on Terminals

Three series of runs were made with both sides of the hot plate under the same conditions, namely:

(1) painted a lamp black.

(2) nickel-plated and polished, and

(3) with the surfaces partly oxidized, before starting the tests.

For the first condition, the paint began to scale off when the temperature reached approximately 100 deg. cent. or about 72 deg. rise, and the test had to be discontinued. Up to this point, the loss by convection was taken as the difference between the total loss and the loss calculated by the standard radiation law, assuming that the emissivity factor was 0.9 of that for a perfect black body, as shown in Fig. 1.

The convection loss points fell practically on a straight line on double-log paper, the equation of the line being $W_c/A = 0.0014\ \theta^{1.25}$ where W_c/A is the watts per square inch of surface and θ is the temperature rise in degrees centigrade. Watts per square inch are plotted against θ in Fig. 5. The test data are given in Table V.

For the other two conditions of the plate surface, the emissivity factor for radiation was found by plotting the total loss in watts per square inch against temperature rise. The difference between this and the convection loss curve found from the black plate divided by the theoretical radiation loss where $e = 1.0$ gives the new emissivity factor. For instance, with the nickel plated surface, the total watts per square inch, when plotted in curve form, are 0.200 for a 50 deg. cent. rise over a 30 deg. cent ambient. Subtracting

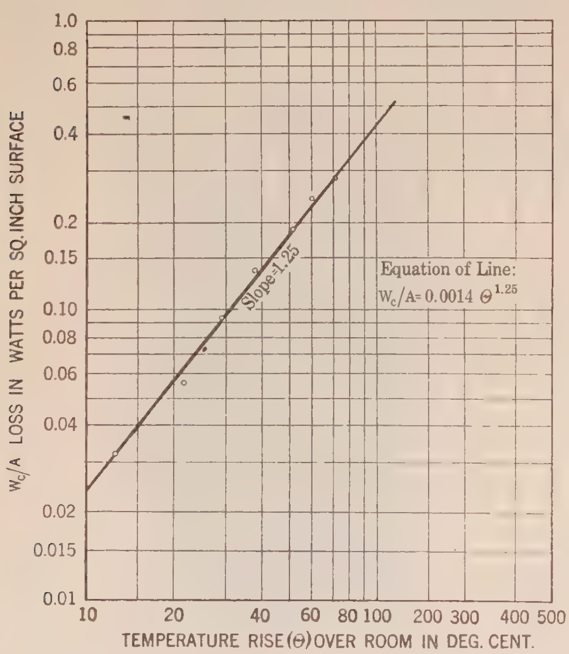

Fig. 5—Heat Loss by Free Convection from a Vertical Plane 31.5 in. in Height and 13.1 in. in Width, Painted Lamp Black

the convection value of 0.182, as shown on Fig. 1, gives a radiation loss of 0.018. But W_r/A, (for $e = 1$) is 0.261, so the emissivity factor $e = 0.018/0.261 = 0.069$ or approximately 0.07 This value of emissivity checks fairly well with that obtained by other investigators. The results obtained with the nickel-plated surface are shown in Table VI.

Up to about 150 deg. cent rise, the convection loss points fell in a straight line on double-log paper, Fig. 6, the slope of the line being about 1.25. From 150 to 200 deg. rise the points gradually drew away from the straight line and at 300 deg. rise the loss was about 25 per cent higher than the straight line.

At first it was thought that this departure from a straight line might be due to a change in the law, but as will be seen later where tests made with the surfaces

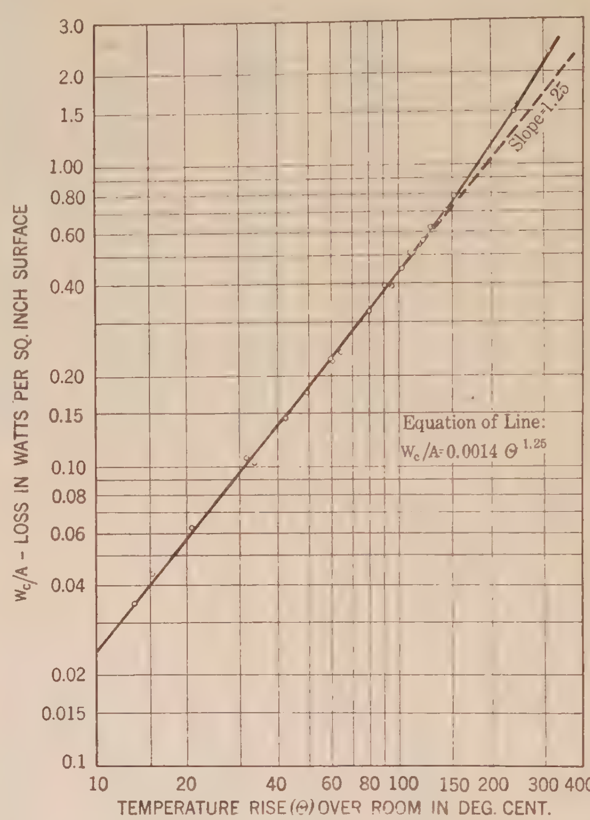

Fig. 6—Heat Loss by Free Convection from a Vertical Plane 31.5 In. in Height and 13.1 In. in Width, Surfaces Nickel-Plated and Polished

partly oxidized did not show this departure, it was apparently due to a gradual oxidation of the surface which at first was not discernible to the eye but which gradually increased the emissivity factor. At 280 deg. cent. rise, the surface became so tarnished that the tests were discontinued.

For the last set of tests the surfaces were painted black and then subjected to a temperature of 325 deg. cent. for about a day to let it get "set" before starting the tests. Some of the paint came off. What remained turned a brownish color.

Tests were taken first with the temperature decreasing and second with increasing temperatures. The emissisity factor, determined as described before, was 0.52. A tabulation of the data obtained with the partly oxidized surface is given in Table VII.

The convection loss plotted vs. temperature rise (Fig. 7) on double-log paper fell practically on a straight line up to 280 deg. cent. rise— as far as the temperature was taken—with a slope of the line of 1.25.

The point to be emphasized is that for a large vertical surface and for the temperature rises used in most electrical apparatus, the loss by convection can be expressed by an exponential equation in which the loss varies as the 5/4 power of the temperature rise. This

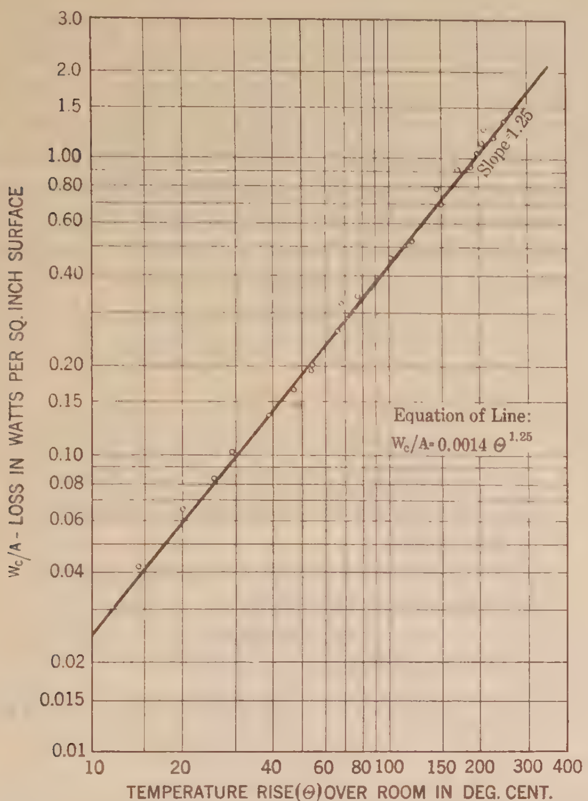

Fig. 7—Heat Loss by Free Convection from Vertical Plane 31.5 In. in Height and 13.1 In. in Width, Surfaces Partly Oxidized before Tests

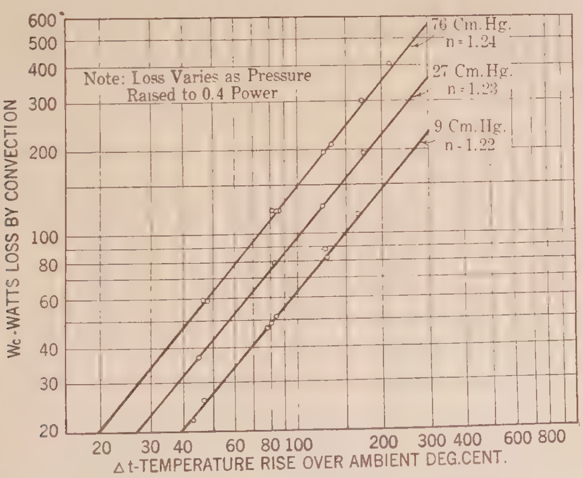

Fig. 8—Effect of Pressure on Loss by Convection, from Data Obtained by C. W. Rice on a Cylinder 1.68 In. in Diameter and 48 In. long

agrees approximately with tests made by Messrs. Ezer Griffiths and A. H. Davis, conducted under the auspices of the Department of Scientific and Industrial Research of England and shown in their Special Report No. 9 issued in 1922 on "The Transmission of Heat by Radiation and Convection." They tested vertical planes of various heights for rises up to 100 deg. cent. For heights of 69 in. and 104 in. they found the value of the exponent to be 1.3 and 1.34 respectively, while for heights less than 69 in. the exponent was 5/4. The constant in their formula was the same for all heights above approximately 12 in. (30 cm.). This checks the writers' experience with various heights of tank surfaces, excepting that the value of the constant found from the tests on the vertical plate was 1.4×10^{-3} when expressed in watts per square inch of surface, or about 9.5 per cent higher than Griffith's and Davis' value (1.28×10^{-3}) for the corresponding height. However, they found that the constant increased quite rapidly for heights less than about 12 in. (30 cm.) as will be seen from the following table.

Height in inches	Constant
11.8 (30 cm.)	0.00128
7.87 (20 ")	0.00175
5.9 (15 ")	0.002
3.94 (10 ")	0.0023
1.97 (5 ")	0.0035

Part II

Effect of Altitude on Temperature Rise of Self-Cooled Transformers and Other Apparatus Having Various Shapes of Surfaces

Self-Cooled Transformers

(*1*) *Radiation.* Altitude, of course, does not affect radiation of heat.

It was shown in Part I that the maximum part radiations plays in practise is approximately 55 per cent at or near sea level for a plain black surface, and that for certain types of complicated tank surfaces, the loss by radiation may be as low as 15 per cent of the total.

(*2*) *Convection.* The general results obtained by various investigators indicate that the loss by convection varies approximately as the square root of the air density. While Doherty and Carter's tests show that the exponent is 0.542, Rice's data[8] obtained on horizontal cylinders tested with the same apparatus show that the exponent lies below 0.5. For example, the data from Rice's Table III have been plotted on double-log paper and are shown in Fig. 8. (Before plotting these results the losses were all corrected for the three nearest pressures, namely, 9, 27, and 76 cm. of mercury.) These results are quite consistent and show that for the cylinder 1.68 in. (4.28 cm.) in diameter and 48 in. (122 cm.) long, the loss varies as the pressure raised to the 0.4 power. The data shown in his Table II for the largest cylinder 4.5 in. (11.42 cm.) diameter by 60 in. (152.5 cm.) long, while not so complete and not replotted, show that the loss varies as the pressure raised to the 0.45 power.

No single test or set of tests in an investigation of

8. Free Convection of Heat in Gases and Liquids, II A. I. E. E. Journal, February, 1924, by C. W. Rice.

this nature is conclusive and the best thing to do in drawing a conclusion is to take a general average of all the available data. In reviewing the results of various investigators, it has been found that the value of the exponent ranges anywhere from 0.4 to about 2/3. Rice's[9] final formula, *i. e.* equation (4), shows that for tall vertical planes, the loss is proportional to the square root of the pressure. The writer has found, as will be shown later, that the square root law agrees best with his experimental observations made in 1915 at three different altitudes on various shapes of tank surfaces.

Based on the square root law, the formula for free convection is:

$$W_c = K\,A\,\theta^{5/4}\,P^{1/2} \tag{8}$$

in which W_c = Convection loss in watts
A = Area in square inches.
K = Constant = 0.0014 at or near sea level.
θ = Temperature rise in deg. cent.
P = Air pressure in atmospheres.

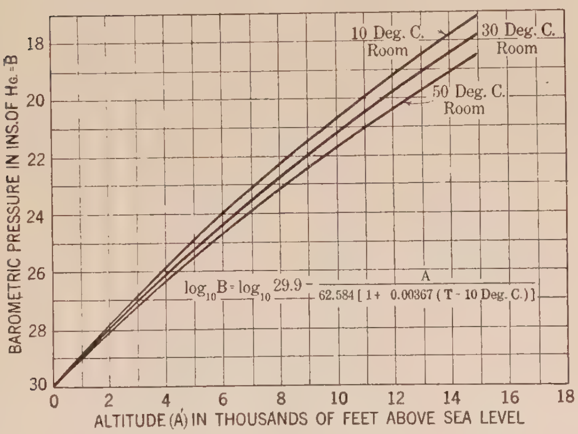

Fig. 9—Variation of Barometric Pressure with Altitude

Expressed in the reverse order, equation (8) becomes:

$$\theta = \frac{1}{P^{.4}}\left(\frac{W_c}{A\,K}\right)^{.8} \tag{9}$$

For a constant loss dissipated by free convection the temperature rise therefore varies inversely as the air pressure raised to the 0.4 power.

Fig. 9 gives curves of barometric pressure in inches of mercury vs. altitude in thousands of feet above sea level for three different room temperatures. These curves were calculated by the Smithsonian Institute's formula:

$$\mathrm{Log}_{10}\,P = \log_{10} 29.9 - \left[\frac{A'}{62.58\,(1 + 0.00367\,(T - 10°\,C)}\right] \tag{10}$$

in which P = Pressure in inches of mercury.
T = Temperature in deg. cent.
A' = Altitude in 1000's of feet above sea level.

Substituting the values of P for various values of altitude (taken from 30 deg. cent. room temperature curve in Fig. 9) in equation (9), we find the following relation between altitude and temperature rise where all loss is by convection:

Altitude in thousands of feet	2	4	6	8	10	12	14
Per cent increase in temperature rise	2.9	5.8	8.5	11.8	14.5	17.9	21.2

It will be noted that the rate of increase in temperature is about 1.5 per cent per 1000 ft. increase in altitude.

Since air density does not affect radiation, the correction is smaller than the above for tanks where part of the loss is dissipated by radiation. For example, for a constant loss the following equation holds approximately for any shape of surface:

$$\theta_1 = \theta + \frac{1.5\,A'\,\theta}{100}\left[\frac{W_c}{W_c + W_r}\right] \tag{11}$$

in which θ_1 = temperature rise in deg. cent. at higher altitude.
θ = temperature rise at lower altitude.
A' = altitude in thousands of feet above sea level.
W_c = loss by convection at the average altitude considered.
W_r = loss by radiation at the average altitude considered.

Table VIII gives the comparison between calculated and tested values of maximum oil and tank rises for three styles of tanks, each of which was heated with a constant loss at Pittsfield, Mass., Boulder and Leadville, Colorado.[10] In fact, all conditions excepting altitude were as nearly the same as it was possible to make them, by using the same temporary housing, meters, thermometers, etc. The tank thermometers, after being

TABLE VIII

COMPARISON OF ESTIMATED AND TESTED TANK TEMPERATURE RISES OBTAINED IN 1915 AT VARIOUS ALTITUDES

			Pittsfield		Boulder		Leadville	
Location			Pittsfield		Boulder		Leadville	
Observed inches of mercury			28.7		24.3		20.7	
Altitude in feet for 30 deg. cent. room			1200.		6000.		10,700.	
Depth of Corrug.	Approx. Average Ratio $\frac{W_c}{W_c + W_r}$		Max. Tem perature Rise deg. cent.					
			Oil	Tank	Oil	Tank	Oil	Tank
9.35 in.	0.85	Test	50.7	47.5†	54.3	51.5	57.3	54.2
		Calc.*	—	—	54.6	51.2	56.8	53.2
3.5 in.	0.65	Test	56.5	52.4†	57.5	53.9	61.7	55.9
		Calc.	—	—	59.1	54.8	61.7	57.2
0 in. (Plain)	0.45	Test	60.	48.5	58.2	46.3	62.8	51.4
		Calc.	—	—	62.	50.0	63.8	51.6

*By equa. (11) and based on rise at Pittsfield.
†By thermometer in inner bend of corrugation.

9. Free Convection of Heat in Gases and Liquids, II A. I. E. E. Journal, February, 1924, by C. W. Rice.

10. See paper by V. M. Montsinger, Effect of Barometric Pressure on Temperature Rise of Self-Cooled Stationary Induction Apparatus. A. I. E. E. Journal, June, 1916.

placed on the surface in Pittsfield, were not disturbed until after the tests were completed at Leadville.

It will be noted that with the exception of the test on the plain tank at Boulder, the tests and calculated values (based on square root law) agree as well as could be expected. The other heat runs with lower rises given in the June 1916 A. I. E. E. paper show approximately the same agreement with the calculated values.

So far, we have discussed only conditions where the loss is constant; *i. e.*, the loss is unaffected by the increased temperature. In transformers where a part (copper loss) of the total loss is increased with temperature, the effect is to increase the percentage somewhat greater than 1.5 per cent for each 1000 ft. increase in altitude. For instance, according to equation (**15**) given in the paper by V. M. Montsinger of June, 1916: to which we previously referred:

$$\frac{\theta}{\theta_s} = (1 + \phi_2/100)\left(1 + \frac{\dfrac{\phi_2\, n\, a\, \theta_s}{100}}{234 + \theta_0 + a\,\theta_s\,(1 - n)}\right) \qquad \textbf{(12)}$$

in which

θ = Temperature rise at higher altitude
θ_s = Temperature rise at lower altitude
ϕ_2 = Per cent increase in temperature rise per 1000 ft. ingoing from lower to higher altitude with a constant loss.
n = 0.8 = reciprocal of exponent in convection formula
a = Ratio of copper loss to total (iron plus copper) loss.
θ_0 = Room temperature in deg. cent.

The following shows the effect of the increased copper loss, due to increased temperature in increasing the rise for various ratios of copper to iron losses as calculated by equation (**12**)

—a— Ratio of Copper Loss to total loss	Increase in Temperature Rise in Per cent.	
	Per 1000 ft.	Per 1000 meters
0	1.5	4.58
0.50	1.62	4.94
0.67	1.65	5.03
1.00	1.75	5.24

The effect of temperature is to decrease the iron loss, but its effect is so small, being in the order of 1 or 2 per cent for a change of 40 to 50 deg. cent., that it can be neglected. Also it is standard practise to express the temperature increase or decrease in per cent of the guaranteed winding rise over the ambient. Since the winding rise over the tank surface is not affected by air density, the 1.5 per cent per 1000 ft. should be reduced by the ratio of the winding rise to the tank surface rise for all self-cooled oil-immersed transformers. Expressed in meters, the general equation for any type of self-cooled transformer or other type of self-cooled stationary apparatus may be expressed, close enough for practical purposes, by:

$$\phi = A''\,N\,S\,(4.6 + a) \qquad \textbf{(13)}$$

in which ϕ = per cent increase in temperature rise
A'' = Increase in altitude in thousands of meters
N = Ratio of tank surface rise to winding rise over ambient temperature.
$S = \dfrac{W_c}{W_c + W_r}$ = ratio of convection to total loss
a = ratio of copper to total loss.

In case it is more convenient to express S in terms of the ratio of surfaces effective for convection and radiation *i. e.* the developed and envelope surfaces we may put

$$S = \frac{45\,D}{45\,D + 55\,Ee}$$

$$= \frac{D}{D + 1.22\,Ee}$$

in which S = shape factor
D = total developed area
E = outside envelope area
e = emissivity factor

If the difference in altitude considered is large, the ratio of 45 to 55 no longer exactly holds because for a given rise the loss by convection decreases as the altitude increase, whereas the loss by radiation remains the same. For example, in going from sea level to 5000 ft. above sea level, the convection loss for a given temperature rise over a 30 deg. cent. ambient is decreased by the factor $\left(\dfrac{25.2}{29.9}\right)^{0.5} = 0.915$. This means that the 45 per cent factor has been reduced to 41.2 per cent. During this time, the temperature rise has slightly increased but the ratio of 42.2 to 55 still holds. For altitude differences of, say, 10,000 ft. (3000m.) and over, it should be satisfactory for practical purposes to use the ratio corresponding to an average altitude of 5000 ft. and write

$$S = \frac{D}{D + 1.33\,Ee}$$

Summary of Parts I and II

1. The loss by free convection is proportional to the temperature rise raised to the 5/4 power.
2. For a vertical tall plane at sea level (and where the emissivity = 0.9) the ratio of losses by free convection and radiation are approximately 45 to 55 respectively.
3. For a given temperature rise the loss by convection is proportional to the square root of the barometric pressure.

TABLE IX
EFFECT OF ALTITUDE ON TEMPERATURE RISE

Type of apparatus	N	S	a	ϕ
(a) Oil Immersed self-cooled transformers	—	—	—	Per cent in copper rise per 1000 m. (approx.)
(1) with plain tanks........	40/55	0.45	2/3	1.75
(2) with corrugated, tubular and radiator tanks..........	40/55	0.80	2/3	3.0
(b) Air-cooled Transformers of Dry Type				
(1) Core wound coils.....	40/55	0.60	2/3	2.3
(2) Form wound coils....	1.0	1.0	1.0	5.25
(c) Air Cooled Reactors......	1.0	1.0	1.0	5.25
(d) Rheostats, Relays, etc....	1.0	0.80	1.0	4.5
(e) Bus bars................	1.0	0.6	1.0	3.5
(f) Water-cooled transformers				0.0

4. For a given loss, the temperature rise (when the loss is by free convection) is inversely proportional to the barometric pressure raised to the 0.4 power.

5. For a constant loss dissipated by free convection, the surface temperature rise increases about 4.6 per cent for each 1000 m. increase in altitude.

6. By assigning practical values to the factors in the formula: $\phi = A'' N S (4.6 + a)$ Table IX gives the effect of altitude on the temperature rise of different types of stationary apparatus.

7. Considered from the standpoint of effect of altitude on change in kv-a. for a given temperature rise, Table X shows the per cent variation for representative cases of the two classes of transformers given under 6 (a) in which it is assumed (1) that the oil rise varies as the total loss raised to the 0.8 power, (2) that the winding rise over the oil is proportional to the square of the load, (3) that the ratio of copper to iron loss at sea level is 2:1 respectively, and (4) that the ratio of the copper to the oil rise is 55 to 40 respectively.

TABLE X
EFFECT OF ALTITUDE ON KV-A. OF SELF-COOLED TRANSFORMERS

Transformer with:	Per cent Decrease in kv-a. per 1000 m.
(a) Plain tanks...........................	1.35
(b) Corrugated, tubular and radiator tank.....	2.3

THE PORTABLE LAMP

Central-Station revenue—that is, revenue from the consumption of electrical energy—is the foundation upon which the tremendous electrical business of this country is built. Any device which increases this consumption is a boon to the whole industry, and even to the nation, provided that there is an accompanying economic advantage of appropriate magnitude. It would take a superhuman analyst to determine the exact increase to the safety, efficiency, comfort and happiness of a household contributed by a portable lamp. Fortunately, portable lamps in the home are still far below the saturation point from the basis of usefulness alone, so that searching anlysis is unnecessary. Even when this point shall be reached there will be justification for more "portables" solely on the basis of ornament.

The portable lamp possesses many advantages both as merchandise and as personal property. It is mobile, it is easily installed, it is the property of the householder, it is useful, it is ornamental, and its cost varies over such a wide range as to suit almost any purse. From a lighting viewpoint it meets many requirements better than any other lighting equipment. It can be obtained in many sizes and various designs. It can be placed where one desires to read, to write, to sew or to play the piano. With fixed lighting equipment these occupations, when dependent on artificial lighting, can be carried on only in certain locations. A convenience outlet can be installed more readily than any other outlet, and several portable lamps may be connected to one outlet if necessary.

A survey made quite recently shows that, solely from a utilitarian viewpoint, the average home can use eight portable lamps, yet that in the middle-class home there is an average of only two portables. On this basis fifty million more portable lamps are needed in the wired homes today, or two hundred million more portable lamps would be needed if all the homes were wired. With wired residences increasing at the rate of one million a year, eight million additional portables are needed every year.

A portable lamp when added to the living room increases the consumption of electrical energy about 100 kw-hr. per residence per year. This means a very great percentage of increase in the net profit per residence per year to the central-station company. A portable lamp in the living quarters is likely to be used several hours on most evenings. Here it is often lighted as an ornament even when not needed for strictly utilitarian purposes. And why not? Lighted ornament is vitalized ornament and has the same esthetic justification as vases or other bric-a-brac. If a portable lamp consumes only 75 watts for an average of two hours per evening, it consumes one kilowatt-hour per week. This is more than an electric washer consumes, and satisfactory portables for a living room cost only a fraction as much as a washer. As a campaign article it is not easy to find its equal.

Recently a number of central stations has conducted campaigns for the purpose of extending the use of portables. The campaigns prove that the portable is easily sold to the householder. Manufacturers and retailers who have concentrated on its sale have met with great success. A department store in Cleveland in one day recently sold two thousand such lamps at an average price of \$20 each, or aggregate sales of \$40,000. These sales made necessary about four thousand new sockets for lamps in a single day, and the central station ought to sell nearly 200,000 kw-hr. more a year owing to this one day's business in a single store.—Reprinted by permission of *Electrical World*, February 9, 1924.

Lightning Arrester Application from the Economic Standpoint

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FOR a good many years, it has been recognized that practise in application of lightning arresters varies and that different engineers determine their choice and use of arresters on widely different base lines. While this may be partly explained by differences in climatic conditions, the variation is without question largely due to the fact that a clear relation has not been established between cost of and benefit from arresters.

Such a relation is difficult to determine because the wide variation in conditions, even in a single locality, makes necessary the consideration of a large number of installations as a unit. Mr. D. W. Roper's extended experience and close analysis of results over many years with thousands of installations shows that even several hundred arrester-years experience cannot be depended upon to give closely accurate results.*

However, the fact that the acquiescence to this lack of a basis for arrester application is an untenable position for arrester manufacturers has been brought definitely to our attention, as a result of the bringing out in 1922 of the two parallel lines of autovalve arresters. Previous to this time, valve type arresters had been made only in the large capacities, intended for protection of important installations, and too expensive or otherwise unsuited for use at the smaller and less important installations. Arresters, designed with the particular object of being low enough in cost to be suitable for use where the valve types were prohibitive, were of so greatly reduced protective value as to be naturally and logically considered as of an entirely different order, just as a fuse is a different order of overload protector from an oil circuit breaker. A comparison between an electrolytic arrester and a former distribution arrester, both for 6600-volt service, will illustrate this.

The electrolytic arrester has a relief voltage at steep wave front of approximately 18 kv., instantaneous value (11.5 kv. for the "AL" type arrester), a resistance of approximately 19 ohms, at ordinary summer temperatures, and a counter voltage of 9.3 kv. The distribution arrester had a relief voltage of approximately 28 kv. and a resistance of approximately 400 ohms. Since this arrester was not of the valve type, it, of course, had no counter voltage. The comparison is well shown by curves 1 and 2 of Fig. 1. For higher voltages the difference is still greater and for this reason we have never felt justified in making the distribution-type arrester for higher voltages.

With the autovalve arresters, the case is quite different. The station type is designed to duplicate the electrolytic arrester in protection. The relief voltage is approximately 21 kv., instantaneous value, the resistance approximately 15 ohms, though this varies with voltage, decreasing as the voltage increases, and the counter voltage is approximately 13 kv. The distribution type is exactly the same as the station type, except that the electrode area is one-fourth as great and therefore the resistance, at the same overvoltage value, is four times as great. The comparison is shown by curves 1 and 3 of Fig. 1, no curve being given for the station-type autovalve arrester, since this closely parallels the electrolytic.

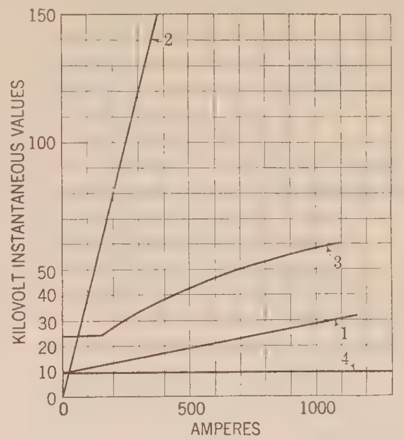


FIG. 1—VOLT-AMPERE RELATIONS SHOWING COMPARATIVE PERFORMANCE CHARACTERISTICS OF SEVERAL ARRESTER TYPES

Curve 1—Standard 6.6-kv. Electrolytic Arrester
Curve 2—Former standard 6.6-kv. Distribution Arrester of the Gap and Resistance Type
Curve 3—Standard 7.5-kv. Distribution Autovalve Arrester
Curve 4—Line Voltage

It is impossible at the present time to express the comparison shown by these curves in terms of directly comparative protective values, but since the object of an arrester is to hold surge voltages down to a safe value, and since this can only be done by permitting surge current to flow through the arrester without excessive rise in voltage, it is obvious that the arrester with the lowest voltage value in the volt-ampere curve is the best one.

It is known that injury by surge voltages begins at some overvoltage value such as 2.5 to 3 times line voltage, and that it increases with increase in voltage, probably faster than in direct proportion to the excess over the minimum injury voltage. It is probable

*TRANSACTIONS A. I. E. E., 1916, Vol. XXXV, p. 655.
*TRANSACTIONS A. I. E. E., 1920, Vol. XXXIX, p. 1895.

Presented at the Spring Convention of the A. I. E. E., Birmingham, Ala., April 7-10, 1924.

that arresters may need to carry surge currents as high as 1000 amperes completely to prevent injury, but that such severe conditions occur only a few times per season, while the less severe surges, requiring the arrester to carry 100 amperes or so, are far more frequent. True relative values cannot be established without more complete data than we now have as to the effect of the surge voltages on insulation and as to the frequency with which surges of different magnitudes occur. For use in applying arresters, however, it may be assumed without fear of very great error that, presuming on the fulfillment of the intention of complete elimination of injury from surge voltages by use of the electrolytic arrester or of the station type autovalve arrester, the distribution autovalve arrester will do one-half as well, that is, in the long-run, eliminate one-half the failures which would occur if no arresters were used. No attempt is made to place a value on the relatively small protection given by the old distribution type, since it is no longer made.

As soon as the changed conditions brought about by the autovalve development were recognized, the need for better general application data was made apparent by a diversity of inquiries, indicating such a wide range of conceptions as to make a logical recommendation seem worthwhile even if it must be based on estimates.

The following attempt to reduce the problem wholly to an economic basis resulted.

General Considerations

The general approach to the problem was an attempt to evaluate the extent and cost of failures to the average system, if entirely unprotected, with the assumption that the yearly expense so incurred may justifiably be spent for lightning arresters. This assumes that the proper application and use of autovalve lightning arresters will reduce the trouble from surge voltages to a negligible quantity. As stated above, it is thought that this is a reasonable assumption, in case the type "SV" station arresters are used. When the type "LV" arresters are applied, as a compromise of protection for the sake of reduced cost, the assumption is that the damage due to surge voltages will be reduced to 50 per cent of the unprotected value instead of practically to zero as with the type "SV" arresters.

Based on records of experience, it is assumed that on an unprotected system in territories of average lightning conditions, 7½ per cent of the transformers installed will be injured by surge voltages each year. Put in another way, each transformer will be injured by surge voltages on the average of once in 13 years.

In calculating the cost of such injuries, two major points were given consideration, namely, the actual cost of restoring service and repairing the injured transformers, and the estimated valuation of the loss of service.

The cost of restoring service and repairing the injured transformer consists in locating the trouble, replacing the injured transformer with a spare unit from stock held for this purpose, transporting the spare transformer to the point of installation and the injured transformer back to the repair shop, and examining, testing and repairing the transformer. Estimates of these expenses are divided into two parts, a more or less fixed charge to cover all except the actual repairs, and the cost of repairs, which is assumed to be equal to 7½ per cent of the initial cost of the transformers.

The evaluation of the cost of loss of service is based on the supposition that cost to the power user must be given the same weight as cost to the power suppliers. It has been many times demonstrated that this idea of determining business policies from the standpoint of the customer is sound. As an average, the cost of power is approximately 5 per cent of the total cost of manufacturing process.

For short time interruptions, the power user's expenses continue without decrease and he thus loses 20 times as much as the power supplier.

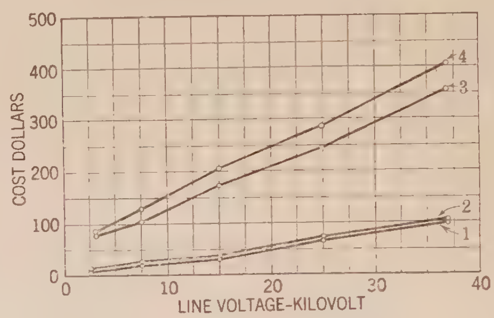


Fig. 2—Arrester Costs

Curve 1—Type *L V* Arrester—First Cost
" 2— " " " —Installed
" 3— " *S V* " —First Cost (Per Phase)
" 4— " " " —Installed (" ")

Based on these two points, the cost of loss of service is taken as 20 times the value of the revenue loss, due to the interruption.

To determine the value of lost revenue, it is assumed that the average duration of a service interruption is 5 working hours, that is, 5 hours always taken from the normal revenue producing period. Average loads are taken to be for lighting service, full load four hours per day and for power service full load eight hours per day and six days per week. The average cost of power to the user is assumed to be 6 cents per kw-hr. for lighting and 2 cents per kw-hr. for power.

As a matter of interest, to check the results of the analysis, the following data are also of interest. Of the total operating company expense, approximately 35 per cent may be taken as interest on the investment and 65 per cent as "operating cost," which includes all other items. Of the total investment 38 per cent may be taken to be in generating station, 18 per cent in transmission lines and substation and 44 per cent in the distribution system. Approximately one half of

the investment in the distribution system may be considered to be in distribution transformers. This means that 7.7 per cent of the gross revenue may legitimately be credited to the initial investment in the distribution transformers.

The cost of arresters used is the installed cost, consisting of initial cost plus an assumed average cost of installation.

Data and results are given below:

Normal Lightning Arrester Costs

Type "LV" Arresters		Type "SV" Arresters	
Rating kv.	Cost Dollars	Cost Dollars	Cost per Phase Dollars
2.5	$5.67	$230	76.5
7.5	17.81	310	103
15.0	30.00	520	173.
25.0	65.00	735	245.
37.0	97.50	1065	355.

Values for cost per phase are given in order that the values for the arresters may match up with the values for single-phase transformers.

Cost of Installation

Type "LV," all voltages, $7.50 per arrester
Type "SV"

Rating kv.	Cost	Cost per Phase
2.5	$25.00	$8.50
7.5	75.00	25.00
15.0	100.00	33.00
25.0	125.00	41.00
37.0	150.00	50.00

Cost of Arresters Installed

Rating kv.	Type "LV" Cost	Type "SV" Cost per Phase
2.5	$13.17	$85.00
7.5	25.31	128.00
15.0	37.50	206.00
25.0	72.50	286.00
37.0	105.00	405.00

These costs are shown on curve Fig. 2.

Transformer Costs

Trans. Rating kv-a.	2,300-220 Volts	6,900-2,300 Volts	12,300-2,300 Volts	22,000-2,300 Volts	33,000-2,300 Volts
1½	33	63			
5	64	97	154	266	
10	102	144	187	204	347
25	197	257	297	392	428
50	324	391	427	532	562
100	486	559	615	741	780
200	708	794	891	1002	1100
250		935	974	1120	1240
500		1360	1420	1622	1740

These represent the normal cost for standard single-phase, 60-cycle distribution transformers, except that these 250-kv-a. and 500-kv-a. prices are standard single-phase, 60-cycle power transformers.

Fixed Cost for Restoring Service

2300 Volts—1½ to 25 kv-a.—1 phase—$10.00 to $15.00
2300 Volts—25 to 200 kv-a.—1 phase— 43.00
High
Voltages—Up to 500 kv-a.—1 phase— 45.00

Gross Yearly Revenue

Transformer Rating kv-a.	Lighting Load Kw-hr. per Yr.	Lighting Load Dollars per Yr.	Power Load Kw-hr. per Yr.	Power Load Dollars per Yr.	Average Dollars per Yr.
1½	2,200	132	2,700	54	90
5	7,300	438	9,000	180	300
10	1,460	876	1,800	360	620
25	36,500	2190	45,000	900	1,550
50	73,000	3650	90,000	1,800	2,700
100	..	..	180,000	3,600	3,600
200	..	..	360,000	7,200	7,200
250	..	..	450,000	9,000	9,000
500	..	...	900,000	18,000	18,000

Cost of Failure

Assumption:

Yearly failures with unprotected system 7½ per cent
" " " complete protection 0 per cent
" " " Type "LV" " 3¾ per cent
Cost of repairs of damaged transformers of original cost .... 7½ per cent
Service loss per failure......... 5 hours
Normal average operating time (yearly)................... 2000 hours
Cost of loss of service equal.... 20 times lost revenue
Average cost of loss of service per interruption equals

$$\frac{5 \times 20}{2000} = \text{..................}\ 1/20 \text{ yearly revenue}$$

Pro rata average yearly share per transformer............ 7½ per cent of cost of one failure.

Cost of arresters for complete protection may equal pro rata yearly cost of failure capitalized at 15 per cent. Type "LV" arresters may cost one half the pro rata yearly cost of failure capitalized at 15 per cent.

Cost of Failure

Transformer Rating kv-a.	Fixed Charge	Repair Cost	Revenue Loss × 20	Total	Total × 0.075 / 0.15
			2300 Volts		
1½	10	2.48	4.50	16.98	8.49
5	11	4.80	15.00	30.80	15.40
10	13	7.65	31.00	51.65	25.83
25	15	14.80	77.50	107.30	53.65
50	43	24.30	135.00	202.30	101.15
100	43	36.40	180.00	259.40	129.70
200	45	53.30	260.00	458.30	229.15
			6900 Volts		
1½	45	4.72	4.50	54.22	27.11
5	45	7.35	15.00	67.35	33.68
10	45	10.80	31.00	86.80	43.40
25	45	19.30	77.50	141.80	70.90
50	45	29.30	135.00	209.30	104.65
100	45	41.90	180.00	266.90	133.45
200	45	59.60	360.00	464.60	232.30
250	45	70.00	450.00	565.00	282.50
500	45	102.00	900.00	1047.00	523.50

Transformer Rating kv-a.	Fixed Charge	Repair Cost	Revenue Loss × 20	Total	Total × 0.075 / 0.15
13,200 Volts					
5	45	11.55	15.00	71.55	35.78
10	45	14.00	31.00	90.00	45.00
25	45	22.30	77.50	144.80	72.40
50	45	32.00	135.00	212.00	106.00
100	45	46.20	180.00	271.20	135.60
200	45	66.80	360.00	471.80	235.90
250	45	73.00	450.00	568.00	284.00
500	45	106.50	900.00	1051.50	525.75
22,000 Volts					
5	45	19.90	15.00	79.90	39.95
10	45	22.80	31.00	98.80	49.40
25	45	29.40	77.50	151.90	75.95
50	45	39.80	135.00	219.80	109.90
100	45	55.80	180.00	280.50	140.25
200	45	76.50	260.00	481.50	240.75
250	45	84.00	450.00	579.00	289.50
500	45	121.50	900.00	1066.50	533.25
33,000 Volts					
10	45	26.00	31.00	102.00	51.00
25	45	32.10	77.50	154.60	77.50
50	45	42.20	135.00	222.20	111.10
100	45	58.50	180.00	283.50	141.75
200	45	82.50	360.00	487.50	243.75
250	45	93.00	450.00	588.00	294.00
500	45	132.00	900.00	1077.00	538.50

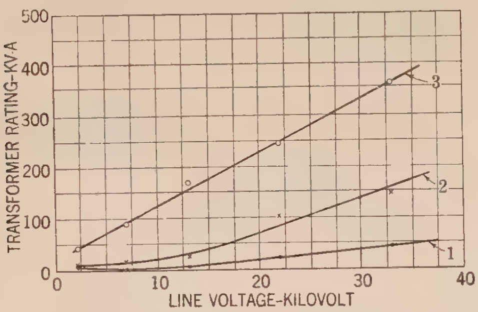


FIG. 3—TRANSFORMER SIZES FOR ECONOMIC BALANCE OF ARRESTER COST AND BENEFIT

Curve 1—Type *L V* Arrester—Grouped Installation
" 2— " " " —Isolated "
" 3— " *S V* "

MINIMUM TRANSFORMER SIZE FOR WHICH PROTECTION IS WARRANTED

The last column in the tables immediately preceding is the capitalized value of the pro rata average yearly cost of failure. This is equal to the maximum permissible cost for an arrester to give complete protection on the basis of an exact economic balance between cost of arrester and savings by use of an arrester. From these values and the figures for the cost of Type "SV" arresters per phase, a determination is made for the minimum size of transformer with which it is justifiable to use type "SV" arresters.

In the same way, the minimum-size transformer, which it is economically justifiable to protect with type "LV" arresters, is determined from the cost of the "LV" arresters and from values equal to ½ the value in the last columns of the tables, showing capitalized value of pro rata average yearly cost of failures.

In the case of network systems in which type "LV" arresters are installed, close enough together so that each transformer is virtually protected by four "LV" arresters, as later discussed under "EXCEPTIONS," complete protection is afforded and the minimum-size transformer which it is economically justifiable to protect with type "LV" arresters is determined from the full values in the last column of the tables, showing capitalized value of pro rata average yearly cost of failure.

Transformer sizes so determined are given in Table I and curve Fig. 3.

Voltage	Transformer Size for Economic Balance: Type "SV" Arrester	Type "LV" Arrester Isolated Installation	Type "LV" Arrester Grouped Installation
2,300	41.5	10	4.0
6,900	90.0	16	1.5
13,200	170.0	27	6.0
22,000	247.0	105	23.0
33,000	363.0	148	45.0

Similar calculations for 25-cycle transformers show that the sizes for economic balance are from 5 per cent to 10 per cent smaller than in the corresponding cases with 60-cycle transformers.

DISCUSSION

To get an idea of the meaning of these transformer sizes and the arrester cost, the following further calculations are made.

On the assumptions made, the average yearly loss per transformer is $\frac{5 \times 20}{2000} \times 0.075 = 0.00375$ times the gross yearly revenue.

Crediting 7.5 per cent of the gross yearly revenue to the distribution transformer, this means that the average yearly loss represents 5 per cent of the income which may justly be credited to that transformer. This in turn means that 5 per cent of the revenue, which may justly be credited to an individual distribution transformer, should be spent for lightning protection.

From the foregoing data, a determination is made as to the percentage which the first cost of the lightning arrester is of the first cost of the transformer of a size for economic balance of cost of arrester and benefits from arresters. The percentage figures are given below.

Voltage	Type "SV" Arrester Percentage	Type "LV" Arrester Isolated Installation Percentage	Type "LV" Arrester Grouped Installation Percentage
2,300	27.2	5.6	10.3
6,900	19.7	9.4	28.3
13,200	21.4	9.8	18.7
22,000	21.9	8.6	17.1
33,000	24.2	10.4	18.3

This means that it is justifiable to spend for lightning arresters for complete protection something like 25 per cent of the initial cost of the transformers to be protected and that in the case of type "LV" arresters, it is permissible to spend from 10 per cent to 25 per cent of the initial cost of the transformers to be protected, depending on installation conditions.

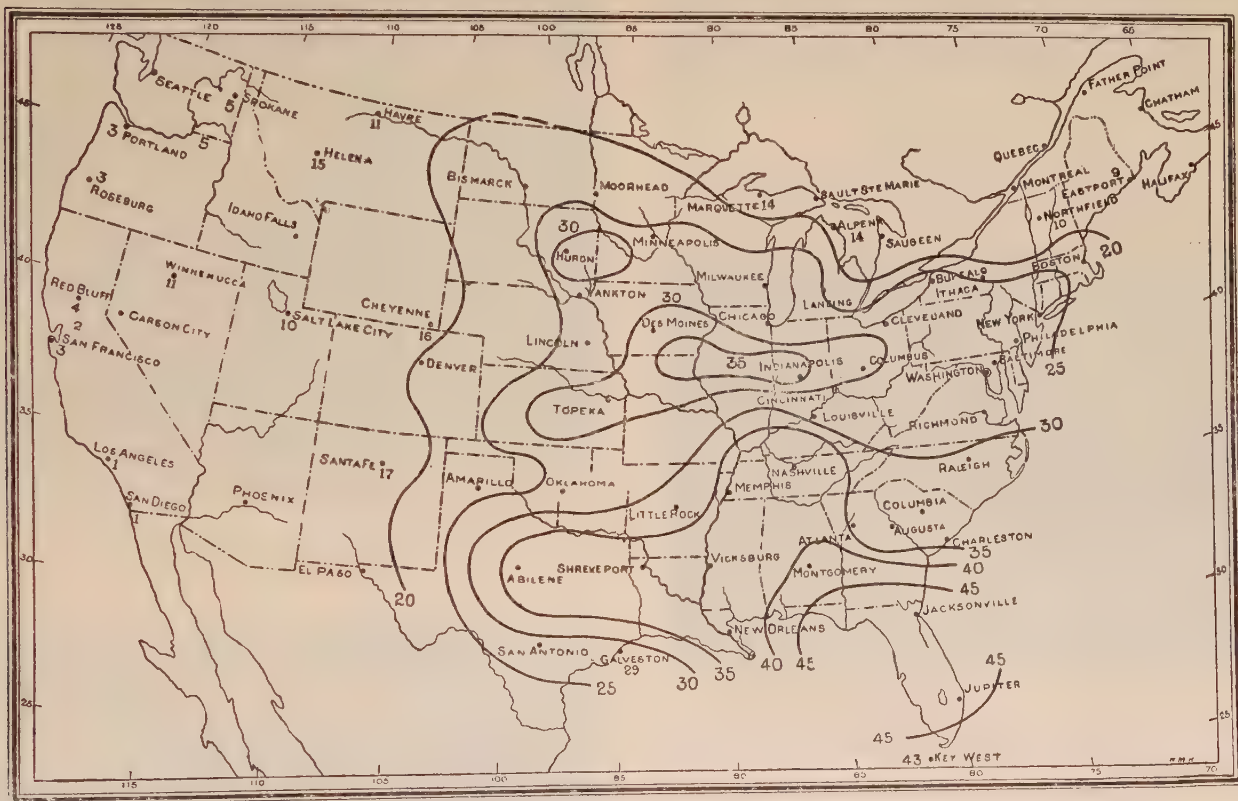
Exceptions

It will, of course, be realized that the conclusions reached in this analysis are only applicable to average cases, and that particular conditions in individual installations will make wide departure from these conclusions permissible. Several of the major exceptions are discussed below.

Although an individual transformer is best protected when the lightning arrester is connected to the system directly at the transformer, considerable benefit is derived from additional arresters, connected to the same circuit, if they are not too far distant. Thus, where the density of installation is sufficiently high, a network can be completely protected by the use of type "LV" arresters.

There are many cases of industrial load in which the actual damage, resulting from loss of service, is not adequately represented by 20 times the cost of the loss of revenue. Examples of this are the kind of rocesses in which a failure of power supply results in loss of valuable material in process, as for example, in a steel mill, a foundry, and a bakery. Under such conditions, it is not justifiable to omit the best available type of lightning arrester under any circumstances. Type "SV" arrester should always be used regardless of other considerations.

There is a tendency in many systems to safeguard loads where continuity of service is vital, by the use of inter-connections which provide for supply to these loads from more than one source. Wherever a transformer failure does not involve a shut-down and is less than that necessary for re-placement of the transformer, the justifiable expenditure for lightning arresters is reduced, the amount of reduction depending on local conditions, as for example, load requirements and the time for restoring service.



Reprinted from U. S. Weather Bureau, Bulletin No. 30.

Fig. 4

The intensity of lightning conditions varies very widely over the country. Ordinarily, for any particular location, a general idea of the intensity of these conditions is in the mind of the operating engineer. An interesting supplement to this direct information is given by the map, Fig. 4, which shows the distribution of thunder storms throughout the United States over a long period of years. Some comparisons between different sections of the country can be made with this map.

Appreciation is expressed of valuable assistance rendered during this study by Mr. E. C. Stone.

Oil Circuit Breaker Investigation
as Carried on with a 26,700-Kv-a. Generator

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ALTHOUGH oil circuit breakers have been used for a number of years and many successful designs produced, the work of the designer has been handicapped by the lack of definite design constants, based on experimental results. On some of the earlier designs, field tests were relied upon for the confirmation of the interrupting rating. Such tests were of great value, but, due to the inherent erratic behavior of oil circuit breakers as a current interrupting device, the data obtained was not usually of a general or fundamental nature. To remedy this situation and to permit continuous and consistent research on the interrupting characteristics of alternating-current circuit-controlling devices, a special testing equipment was installed.[1]

Testing Equipment

This station contains a three-phase specially built

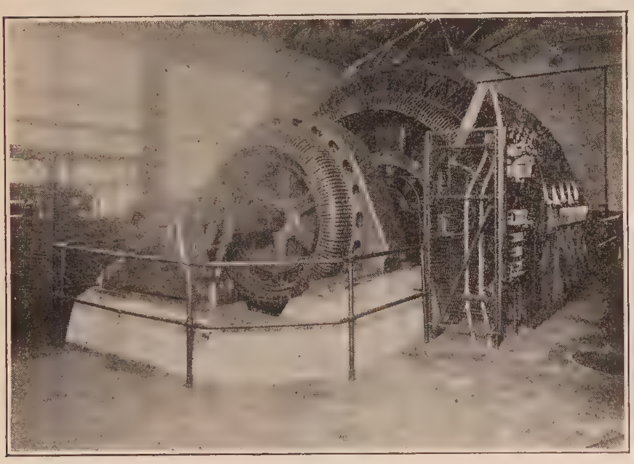

Fig. 1—Testing Generator at 1-10-26,700-300-25 13,200/7620/6600/3810 Bldg. 60E

26,700-kv-a. 25-cycle alternator of low reactance. The windings are arranged for connection to give 13,200, 7620, 6600 or 3810 volts. A three-phase 1500-horse power direct-connected induction motor is used as the driving power. The generator and driving motor are shown on Fig. 1.

The short-circuit current supplied on short circuit is controlled by means of reactors having ten taps and a maximum value of 6.1 ohms per phase.

In addition to the generator, high-voltage transformers of low reactance are provided. These transformers permit three-phase testing at any voltage up to 44 kv. and single-phase testing up to 132 kv. These transformers with the bus construction are shown on Fig. 2.

The measuring equipment, in addition to the usual

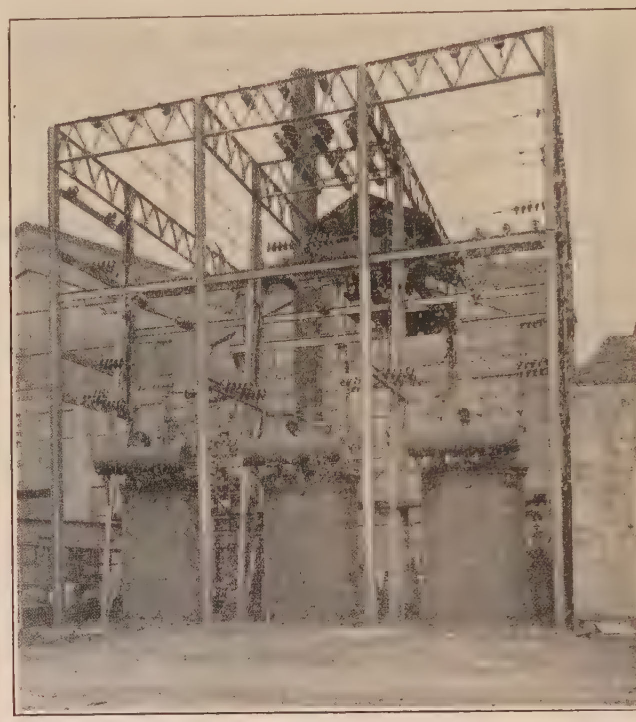

Fig. 2—High Voltage Testing Equipment of High Capacity Testing Station Bldg. 60 E

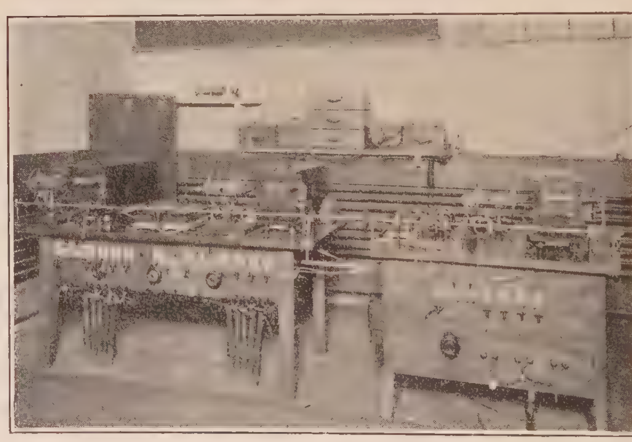

Fig. 3—Three Oscillographs on One Driving Shaft as Used in Control Room of High Capacity Testing Station, Bldg. 60 E

meters, consists of three oscillographs, pressure recorders, speed recorders, and such other apparatus necessary for the collection, analysis and measurement

1. C. E. Merris, *General Electric Review*, June, 1923.

Presented at the Spring Convention of the A. I. E. E., Birmingham, Ala., April 7-10, 1924.

of gas. The oscillographs are shown on Fig. 3. The general diagram of connections of the station, together with detailed connections of the oscillographs, is shown in Figs. 4 and 5.

This equipment will produce short circuits approximating 300,000 kv-a., three-phase, at 13,000 volts.

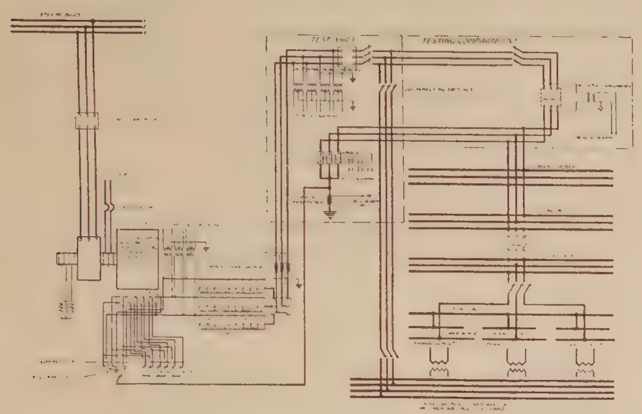

Fig. 4

The equivalent three-phase kv-a. at 13,200 volts can be increased to approximately 600,000 kv-a. by single-phase test to ground at 7630 volts. Approximations of short circuits very much higher than 600,000 kv-a. can be obtained by testing one break on single-phase tests.

In order to provide protection against injury to the observers from burning oil or flying particles during the tests, a bomb-proof of brick, steel and concrete was constructed. This bomb-proof has one side open so that observations can be made from a safe distance.

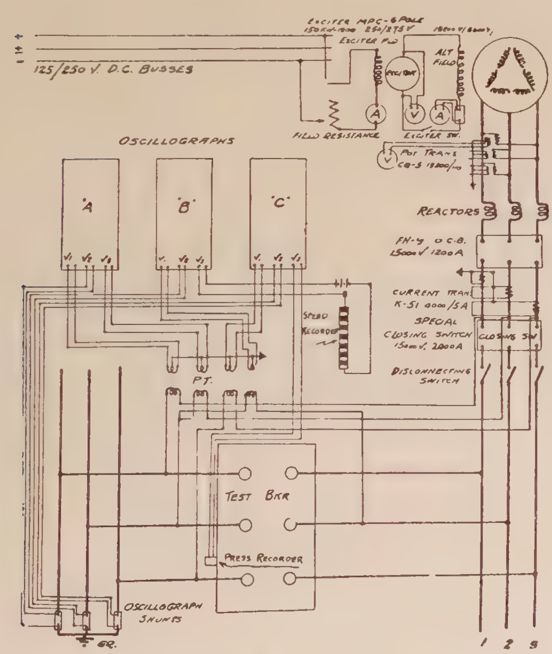

Fig. 5

It is the purpose of this paper to discuss some of the characteristics of oil circuit breakers as determined from the tests with this testing equipment, and to indicate as far as possible the effect of some of the factors considered.

The Factors Investigated

Break Distance. The satisfactory operation of any oil circuit breaker depends upon the break distance. This break distance must be ample to interrupt the arc under the severest condition of operation or there will be a permanent gas generation which will quickly result in the destruction of the breaker. The required break distance for any given voltage and interruption is determined by the circuit connections, *i. e.*, grounded or ungrounded, power factor, connected shunt load, amperes interrupted, pressure in the oil tank, tank cross-section, etc., and it is evident that to have an absolutely safe breaker, the worst conditions must be assumed. This condition is fortunately a dead short circuit at the generator terminals on an ungrounded system without shunt load, and it is under these conditions that our rating tests are made. If the breaker is to be used on a line where easier conditions exist, then the breaker may have a larger factor of safety than under its rating condition. Cases have been observed where the break distance of breakers was inadequate for operation in generating stations but proved to be satisfactory in substations because, due to the arrangement and connections of the system, the arc length obtained for a given ampere interruption was less.

Speed of Break. The interrupting capacity of a breaker depends upon the speed of break, but one cannot say that the higher the speed, the greater the interrupting capacity in every case. The interrupting capacity of a breaker depends not only upon the quantity of gas generated, but upon the speed of generation, and it may well be that a given breaker, if operated at higher speed will have a less interrupting capacity. The higher speed may well result in a longer arc, in more gas and more pressure than if operated at the lower speed, and this condition has been observed in test. Before we can determine the effect of a speed change, we must know many factors relating to that particular breaker.

In what has been written about speed of break, it has been assumed that the moving contact was traveling at practically uniform speed. As a matter of fact, however, every breaker will have its own speed characteristic and this characteristic at no load may be decidedly different from the full interrupting capacity speed. In fact, at some load, the speed may not only slow down but actually stop and reverse in direction so as to reclose the breaker. There are several reasons for this behavior and none of the plain break breakers can be considered as entirely unaffected by it. Whether the defect is a serious one in any particular case can only be determined by actual test of the breaker under severe conditions.

In the case of fairly low voltage breakers, operating to interrupt large current, the actual speed of the moving contact may have little relationship to the interrupting capacity of the breaker, as such breakers interrupt the arc by the magnetic blowout effect instead of the physical separation of contacts. It may be found, however, that the heaviest stress is not produced by the largest current interrupted and that more gas and a greater pressure is produced when interrupting a lesser current than that of the maximum rating. It is needless to say that the breaker must be safe when interrupting these smaller currents and that this fact must be considered in the rating of the breaker.

Oil Head. The head of oil over the contacts influences the interrupting capacity of the breaker, as it largely determines the pressure above and below the oil surface and therefore tank rupture. It also determines the arc stabilizing, shock to the entire breaker structure, oil throw and gas ignition. Too much oil in the tank is as bad as too little. The correct quantity to use can only be determined by repeated tests at all loads up to the interrupting capacity rating of the breaker. In testing oil circuit breakers on skids, it is frequently noticed that the breaker jumps clear from the floor at the instant of interruption. This, of course, is due to the kinetic energy in the oil as a result of being blown by the arc gas, which is expended when the oil mass strikes the top of the breaker. This shock may be so severe as to break the top casting of the breaker.

Air Space above the Oil. The proper air space above the surface of the oil will vary with each individual breaker and the correct quantity has to be settled by the designer as a result of his observations of the action of various breakers under test. It should be noted that the tank pressure is not the only factor to be considered as affected by the air space, as there are also oil throw, arc stabilizing, secondary explosions, and gas ignition. Oil head and air space must be considered together.

Various Types of Venting. The venting of an oil circuit breaker is an important problem, as it affects the oil throw, tank pressure, and gas ignition. It has come to be recognized that the modern high class breaker must limit the ejection of oil or incandescent gases into the room at the breaker, and in order to accomplish this end a thorough investigation of the problem was made. As a result of these tests, the oil-throw problem is well in hand but it should be realized that small and inexpensive breakers will not be free from oil throwing at extreme loads. The non-oil-throwing breaker is a comparatively modern product, and the vast majority of breakers now in use were designed with little regard to the question of oil throw. Hence their construction does not readily lend itself to the rebuilding into a non-oil-throwing type.

Determination of Allowable Tank Pressure. In oil circuit breaker design, the maximum instantaneous pressure to which the structure may be safely subjected is of great importance, as it determines the safe interrupting capacity of the breaker. The foregoing statement refers particularly to those breakers having tanks of other than circular shape. Such information can only be had as a result of repeated tests when utilizing suitable recording instruments in connection with a source of power such as our large testing generator. Any calculations of static stresses which the structure will withstand are difficult to make and the results obtained, due to the lack of proper constants, are wide from the actual permissible pressures.

Method of Tank Construction and Best Material. Here also the use of the testing generator was invaluable as it settled questions which had been debated previously, but without any definite result, and the results of these tests are sure to show up in future records of performances.

Methods of Tank Support. Definite results have been obtained from the investigation of the method of supporting the tank and in all new breaker design advantage is taken of the findings from the tests.

Tank Lining Investigation. The question of the lining of the oil tank and, in fact, whether it should be lined or not, is one of great importance. The tests made with the large testing generator have definitely answered this question. They have shown that linings are in most cases necessary and that there is a decided difference in the efficiency of various linings. Just why one type is best in one case and another type better under other conditions has been determined.

Contact Investigation. One of the most important questions in oil circuit breaker construction is that of the contacts, both main carrying contacts and arcing contacts, and more attention is given this one feature than any other single feature entering into the breaker construction. The investigation of this feature included not only the burning and carrying capacity of the contacts, but also the heat generating and dissipating characterisitcs of the connected studs and bus bars, the effect on the brush by the shock of closing of the breaker, the degree of over-travel the brushes will stand, the permanency of the brush structure, the specification for the brush metal to give best results, the best contact pressure and area of contact, and the design of contacts so that they will not be affected by the magnetic stresses under short-circuit condition.

The burning of the contact members of an oil circuit breaker is a very important factor in the entire oil circuit breaker investigation and probably receives more attention, while the breaker is undergoing tests, than any other single feature. Repeated tests are made at the standard number of duty cycles. This means that the breaker is tested in closing on a short circuit, as well as opening the short circuit and under duty conditions, the equivalent of the rated interrupting capacity of the breaker and worst possible circuit conditions. Contacts are also tested to destruction in order that we may

have definite information as regards the maximum continuous duty the contacts will stand.

The brush heating is the chief feature of the circuit breaker which may be adversely affected by the action of the operating company. This may come from the improper adjustment of pressure at installation, by the use of insufficient bus bars section, by the heat insulation of that section, by the insulating tapings, by the running of cables carrying large currents causing eddy current losses, by installation of tanks close together, which decrease heat radiation, and by the installation in unventilated cells in locations where the ambient temperature is high.

Ability of Breaker to Withstand the Shock of Oil Throw. Without the generator of large capacity, it

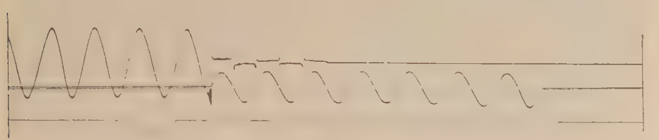

Fig. 6

would have been impossible to test for this condition which in the past has been responsible for serious breakages.

Reclosing Characteristics of the Breaker. The conditions under which the breaker contacts slow up or actually reclose have received special consideration and tests and facts have been discovered which were not suspected at the time of starting the investigation.

Oil Throw and Gas and Oil Ignition. These features have been investigated in the case of the old style breakers; the newer breakers do not have these defects. It is, of course, impossible to stop the throw of oil and gas in the old type breakers without practically rebuilding them; however, the tests have shown how it would be possible to construct the breakers and permit the oil throw while preventing ignition.

Secondary Explosions. Attention was given to the cause and magnitude of secondary explosions. The tests were made with a bomb and also upon full-size oil circuit breakers and the large testing generator. Oscillograms, Figs. 6 and 7, show such a secondary explosion. They show that the breaker interrupted the circuit with ease, that in 0.014 sec. after interruption, pressure developed in the air space (Fig. 6), that the maximum pressure was reached in 0.004 sec., that the pressure below the oil, due to the necessary acceleration of the oil mass, was delayed 0.007 sec. behind the air space pressure. The breaker was not injured. These secondary explosions are nearly always caused by a static spark igniting the explosive gas mixture and may come while the breaker is open or closed. Their cause is well understood and if the station operator takes proper care of the breakers, there should be no such explosion in the newer breakers.

Acceleration and Retardation of the Moving Contact Member. The acceleration of the moving contact member under short-circuit conditions is extremely important and equally important is the retardation, especially in the case of the explosion chamber breakers. With these latter breakers any desired speed of opening may be readily obtained. The breakers are specially designed to give the desired opening speed and means have been developed to satisfactorily decelerate moving parts.

Investigation of Magnetic Stresses Produced in the Breaker. Magnetic stresses may cause the lifting of the brush or the throwing back of some types of arcing contacts, at "Make." Such stresses may also cause movement of bushings and studs. The current limits of various designs have been determined and designs for higher duty developed.

Arc Stabilizing Tests. If the contact blocks under oil are not separated a sufficient distance or there is insufficient distance between these blocks and the metal part of the operating rod or cover or tank, an arc is liable to be stabilized across these insufficient distances and cause the destruction of the breaker. The safe distances depend upon the voltage, circuit conditions and amount of current interrupted and each type of breaker is tested many times under the most severe condition of operation, in order to prove that the distances to prevent stabilizing are ample.

Oil Viscosity and other Oil Characteristics

The characteristics of the oil used in oil circuit breakers are important factors in the satisfactory operation of the breaker, and the oil supplied with the General Electric oil circuit breakers is rigidly held to specification. Miniature tests are only made in the research laboratories, but tests are also carried out with the large testing generator. That oil is best which

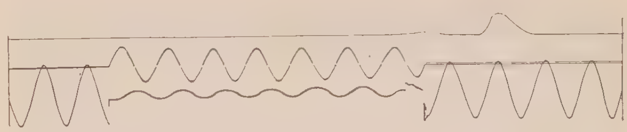

Fig. 7

produces the least quantity of fixed gas for a given interruption, which has the least carbon production, the most suitable oil viscosity for the particular breaker in which it is to be used, the highest dielectric strength for the given interruptions, the smallest quantity of oil vaporized, the greatest percentage carbon precipitation, the least absorption of moisture, and the highest flash point. The oil affects the circuit-breaker operation in ways little realized by those not intimately connected with the breaker investigation.

Other arc-extinguishing liquids, as well as the oil, are under constant observation by means of the full-size tests. Miniature tests show interesting results, but definite conclusions can only be obtained by

comparing such tests with tests made on full-sized apparatus.

Duty Cycle Tests

All breakers are tested at the new proposed duty cycle, *i. e.*, two open-close-open at the rated interrupting capacity, or if that cannot be obtained, at capacities which may be used to interpolate and thus obtain the full duty.

Tests have also been made at duty cycles other than standard, in order to determine the relative severity of these supplementary cycles.

Gas Production and the Resulting Stresses Upon the Breaker. An extended investigation into the gas generated by the arc has been carried on for months past with the large testing generator and will be continued for months to come. In these tests, the gas volume generated, the speed of generation, the pressures above and below the oil level, the current and voltage at the break, are all recorded on the oscillograph. The effect on the breaker structure are also recorded. These data

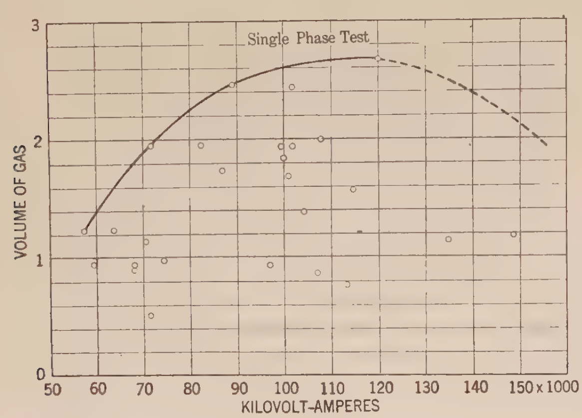

Fig. 8

are used in obtaining an empirical formula with which to calculate the interrupting capacity of any existing breaker and the design information for any new breaker of any proposed interrupting capacity. In this connection, it can be stated that, theoretically, the quantity of gas generated depends upon a large number of variables. For instance, the r. m. s. current and voltage varies throughout the arcing period, the current decreasing, the voltage at arc increasing with the time. The resistance of the gas stream and the dielectric strength of the gas vary with the pressure and temperature of the gas, and since the gas generation is a heat phenomena, this pressure affects the $I^2 R$ losses and the dielectric strength affects the duration of arcing. Then there is the effect of the magnetic blow-out which affects the arc duration. The power factor and shunt load both affect the recovery voltage, which in turn affects the re-establishment of the arc at each zero value of the current wave, the available stored energy—electromagnetic and electrostatic—in the circuit, which may be discharged through the arc at the zero current value and aid re-establishment of the arc and other causes—all of which combine to make the gas production extremely fluctuating. The extent of this fluctuation is shown in Fig. 8, on which has been plotted the volume of gas generated and current in the arc at definite voltage and circuit conditions. It is evident that our empirical formula for interrupting capacity determination must be based upon the curve of the extreme points, as plotted from the tests, and that such a curve can only be obtained by means of a large number of tests made with a generator able to produce the conditions at the desired rating.

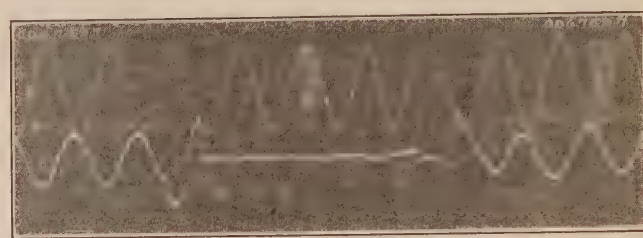

Fig. 9

Investigation into the Action of the Oil Circuit Breaker under Various Conditions. That the action of the oil circuit breaker is very erratic is soon realized when one attempts a systematic investigation of its action. Individual short circuits vary widely in effect, when all conditions of the short circuit are made as nearly identical as possible. That is, you may take a given generator, running at a definite speed, and excited to the same voltage, with the same impedance in circuit, and short circuited by the same breaker, under the same conditions of grounding, and the gas generated may vary

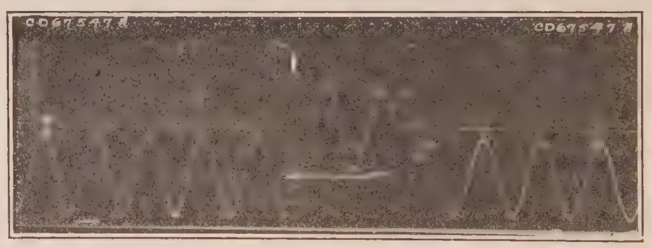

Fig. 10

several hundred per cent. The gas generated is the final measure of the efficiency of a given breaker, but the speed of generation must, of course, be taken into consideration. If fluctuations to the extent indicated above are observed under constant and controlled conditions, what must be the variation during the ordinary short circuit on commercial systems where the field excitation, power factor, shunt load, conditions of grounding, and other factors vary widely?

In general on commercial-systems, the factors mentioned above are usually combined so that the interrupting conditions are less severe than they are under the

controlled conditions of test. Therefore, it is safe to assume that breakers which will pass tests with the testing generator equipment will give satisfactory service under normal operating conditions. By normal operating conditions is meant conditions limited by the normal generator and circuit characteristics and would not, for instance, include a heavy lightning stroke or cross with a higher voltage line.

The service condition where an oil circuit breaker in a generating station controls a single feeder is, of course,

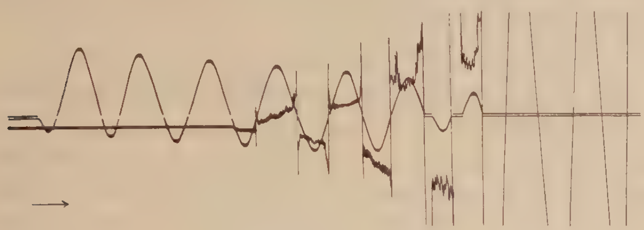

Fig. 11

in general equivalent to the condition obtained with the testing generator and should produce equivalent results.

There is, however, considerable difference in the operation of breakers on ungrounded systems, as compared with the operation on systems with the neutral grounded and a short circuit to ground.

Oscillogram Fig. 9 shows a short circuit upon an ungrounded system and oscillogram Fig. 10 shows a short circuit with the same apparatus upon the same system with the neutral grounded and a ground at the breaker.

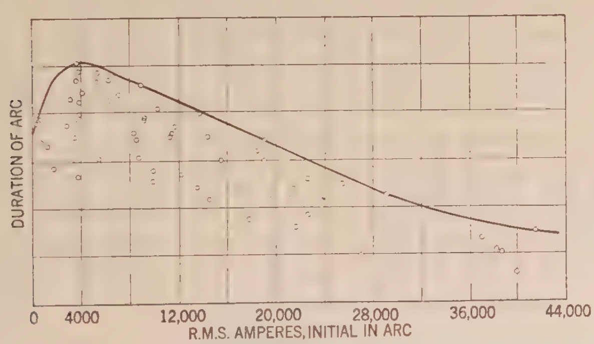

Fig. 12—Curve Showing Arc Duration as a Function of Current Interrupted by a Type F K Oil Circuit Breaker (Plain Break) Test Conditions Equivalent to Those Prevailing at Baltimore Test but Made on Basis of 13,200 Volts, 3 ϕ

The feature to be noticed is the recovery voltage, which is characteristic of the two conditions and is considerably greater in the case of the ungrounded system. The greater recovery voltage means a longer arc and more gas generated in the breaker before final interruption of the circuit. By recovery voltage is meant the instantaneous voltage rise at the instant of circuit interruption, that is, it is the voltage which tends to re-establish the arc at the zero value of the current wave. In this connection, it might be said that while we state broadly that the interruption of the circuit always takes place at the zero value of current, this statement should not be taken too literally. It takes a certain voltage to maintain an arc; the longer the arc, the higher the required voltage, so that a time must come at every operation when the circuit tends towards interruption and before the absolute zero value is reached. This fact will largely account for the "kick" which will be made manifest by the use of spark gaps, but is not shown by the oscillograph, it being a steep wave-front phenomenon. The action of this phenomenon, however, is to aid in re-establishing the arc.

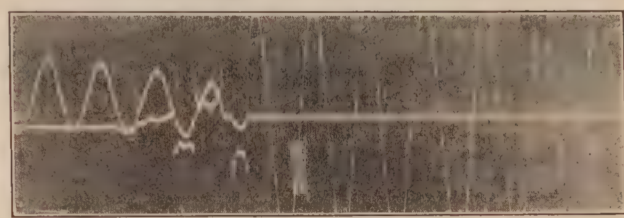

Fig. 13

That the circuit may be re-established some considerable time after the zero current value, is shown in oscillogram Fig. 11, in which case about 60 electrical deg. have elapsed before re-establishment. This case is not unusual, but on the contrary, is quite frequently noticed. The arc is, of course, an energy phenomenon and the current and voltage in the arc are substantially in phase, but at the instant of final circuit interruption there is a change in the relationship of the two and the lag of current is then determined by the circuit as a whole. This is important, because it in a way explains why the low power factor conditions are the harder

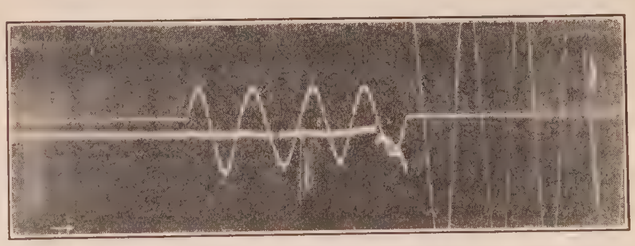

Fig. 14

to interrupt. At zero current value and 90 deg. lag, the maximum voltage is available to re-establish the arc, while at unity power factor there is zero voltage at zero current. This difference caused by power factor variation is really one of time, only because if we assume a case of unity power factor and a 25-cycle circuit, the same voltage is applied at the expiration of 0.01 second, as would have been applied instantaneously at zero power factor. During this 0.01 second, the gas has had a chance to cool, thereby increasing its dielectric strength, and the gap has been increased (assuming an opening speed of 5 ft. per

second) by 0.6 in. Both of these factors act to increase the interrupting capacity of the breaker in the case of unity power factor.

Investigation of the Magnitude of Current Interrupted upon Circuit Breaker Action. In the case of fairly low voltage, the magnetic blow-out effect has to be considered in connection with the interrupting capacity of the breaker. Curve No. 12 shows such a study.

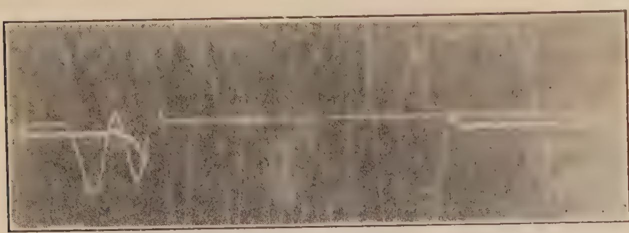

Fig. 15

This curve shows that the maximum arc length corresponds to a fairly definite current value and that any increase in current above this value acts to decrease the arc duration.

The logical deduction is that at some current value, less than the maximum interrupting rating, the breaker may fail. This deduction is correct and many breakers

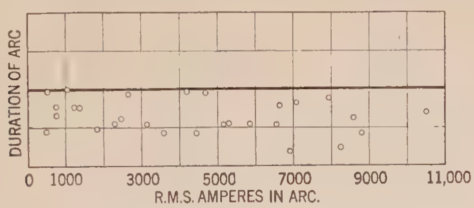

Fig. 16—Curve Showing Arc Duration as a Function of Current Interrupted by a Type F K H Oil Circuit Breaker (Explosion Chamber) Test Conditions Equivalent to those Prevailing at the Baltimore Tests but Made on the Basis of 15,000 Volts 3 ϕ

are undoubtedly stressed more at part rating than at their maximum rating.

Comparison of the Plain and Explosion Chamber Breakers. Oscillogram Fig. 13 shows a plain break interruption, and Curve Fig. 12 shows the plot of arc lengths and currents on such a breaker. The erratic behavior of the plain break breaker is striking but is characteristic of this class of breaker. Oscillogram Fig. 14 shows an explosion chamber interruption in the same tank at substantially the same current and with the same mechanism, while oscillogram Fig. 15 shows the same explosion chamber breaker interrupting substantially double the current at 1:73 times the voltage of the plain break breaker in Fig. 13.

Curve Fig. 16 shows the plot from tests of half cycles and currents of an explosion chamber breaker.

The foregoing oscillograms and plots are characteristic of the two types of breakers and comments are not needed as to the story they tell in reference to breaker efficiency, an efficiency which increases with the voltage increase in the case of the explosion chamber breaker.

Testing of Breakers to Operate under Special Conditions. For this class of work the testing generator equipment is invaluable, as we are able to obtain results and definitely settle questions which it would be impossible to do without such an equipment. Miniature tests are of little value unless they can be compared directly with tests made on regular apparatus under operating conditions.

In order to be proven safe, every breaker must be tested under full maximum operating conditions or must be compared with a similar breaker which has operated under these conditions.

Conclusions

What has preceded shows the large number of variables which enter into the determination of the oil circuit breaker interrupting capacity. It shows that each variable depends upon the others and that the breaker as a whole must be judged from results obtained when actually performing under loads which vary from the smallest up to its maximum rating and under repeated operations at each value. A single shot at any particular load is far from conclusive and the only safe rating is that obtained from plotting many tests made at all capacities.

For this work, the large testing generator has proven invaluable. It has made clear phenomena previously not understood. It has brought out facts not dreamed of until they were shown up by the tests. It has pointed the way as to what features to avoid and what improvements to make, and its influence is showing in the design and performance of our breakers and will continue to show its value in the research which is already planned for years ahead.

GIANT SEARCHLIGHT FOR UNITED STATES

The latest addition to the U. S. Coast Defense is a giant one billion-candlepower electric searchlight which weighs eight thousand pounds and is ten feet in diameter. It is mounted on a skeleton tower 100 feet tall patterned after the towers carrying heavy electric transmission lines. The balance of this huge searchlight is so accurate that two men operating a system of levers can raise or lower it at will in less than two minutes.

LIGHTING THE FIRST STORE BY ELECTRICITY

The first electric light to be used in any retail establishment blazed forth on December 26, 1878, in John Wanamaker's department store in Philadelphia. People watching the light being turned on laid wagers that it could not be kept lighted. They also predicted that a store which used such surprising innovations would cease to be. The electric light which was turned on in the Wanamaker store, was a Jablochkoff candle. It was one of the earlier types of the electric arc light.

The Hysteresis Character of Corona Formation

BY HARRIS J. RYAN and HENRY H. HENLINE
Fellow, A. I. E. E. Associate, A. I. E. E.
Both of Leland Stanford University

YEARS ago in studying the nature of corona losses occurring from a small high-voltage laboratory line the cathode ray tube was used to observe the cyclic relation of corresponding instantaneous values of line voltage and charge.[1] It was found that the sides of the resulting diagrams were practically parallel, causing them to resemble hysteresis cards. The significance of this was not recognized at the time. More recently two items were encountered that have called for a critical study to be made of these same

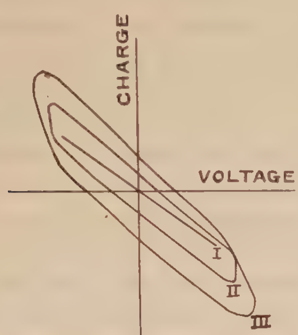

FIG. 1

diagrams: (1) the value of the power lost through corona from a transmission line closely approximates that given by the product of the charging current and the voltage in excess of the critical voltage; (2) the dominating importance of the crest voltage in relation to corresponding corona loss. These items clearly indicated *the hysteresis character of corona formation.*

Fig. 1 is a copy of Fig. 6 which appeared in the paper referred to above. The diagrams in this figure were obtained while using a pair of wires 0.085 inch in diameter spaced 12.5 inches apart. Card I was taken at 44,000, card II at 53,400 and card III at 64,000 root-mean-square approximate sine wave volts.

The heavy line diagram in Fig. 2 represents the general form of card obtained in such cases. When the crest voltage is below the value E_0, the loss is zero, and the card is a straight line lying on the line $X\,Y$. At a crest voltage very slightly below E_0, the card is the line $g\,h$, and the maximum charge is Q_a. The charge varies directly with the voltage, and all the energy stored in the charge Q_a at the critical voltage, E_0, is returned to the source when the voltage is reduced to zero. As the voltage is increased beyond the critical value, E_0, to the value E and again reduced to E_0 the charge increases because of corona formation from the value Q_a to that of Q_b. The net result of this action is to increase the charge permanently through the succeeding half cycle by the amount $Q_b - Q_a$. Assuming that the cycle has now been formed up, the same thing occurs when $-E_0$ increases to $-E$, the isolated charge $Q_b - Q_a$ having a value of $o\,i$ is first discharged without return of energy and then built up to the same negative value, $o\,j$. Then as the cycle proceeds while $-E$ changes again to $+E$ the charge Q remains at all times reduced correspondingly by the same amount $Q_b - Q_a$. Thus a loss of energy per cycle is caused through the corona formation determined substantially by the area of the card $a\,c\,d\,f\,a$.

From these boundaries the value of the power lost in corona may, therefore, be written as the product of the frequency and the $E - Q$ area determined by the corona cycle. Since the areas

$a\,c\,i\,j\,a = a\,c\,Q_c\,Q_a\,a$

$$P = 2\,f\,E\,(Q_c - Q_a) \text{ and} \tag{1}$$

because

$$Q_a = E_0\,C;\; Q_b = E\,C;\; Q_c - Q_a = 2\,(Q_b - Q_a)$$

it follows that:

$$P = 4\,f\,C\,(E^2 - E\,E_0) \tag{2}$$

wherein

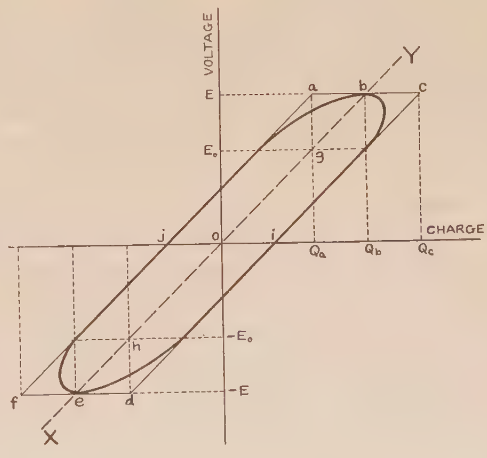

FIG. 2

P is the value of the corona loss in watts per conductor.

f is the value of the frequency.

E_0 is the crest value of the critical voltage to neutral.

E is the crest value of the line voltage to neutral.

C is the capacitance in farads of one conductor to neutral.

The reason for the close agreement of the values of corona losses and their corresponding products of line

1. Harris J. Ryan, A Power Diagram Indicator for High-Tension Circuits, TRANS. A. I. E. E., Vol. 30, 1911, pp. 1089-1113.

To be presented at the Pacific Coast Convention of the A. I. E. E., Pasadena, Cal., Oct. 13-17, 1924.

charging currents and line voltages in excess of critical voltage may now be made apparent, *i. e.*

$$P' = i_c\,(e - e_0) \text{ or}$$

$$P' = 2\,\pi\,f\,C\,e\,(e - e_0) \text{ or} \tag{3}$$

$$P' = \pi\,f\,C\,(E^2 - E\,E_0) \tag{4}$$

The value of P is only $4/\pi = 1.272$ greater than that of P' which accounts for the close proximity of *measured corona loss* P_0 and the corresponding value for the product of charging current and voltage in excess of critical voltage as in equation (3).

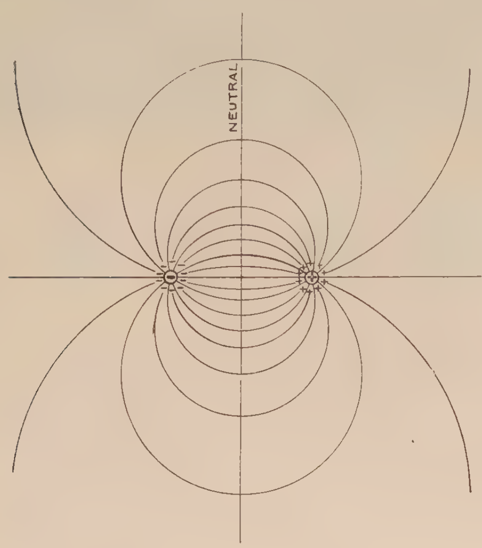

Fig. 3

The form of these *voltage-charge* diagrams produced by corona is specific and may be clearly understood by a study of the ionization existing around a conductor subjected to high voltage. If the voltage does not at any time during the cycle exceed the value E_0 in Fig. 2, there is no corona loss and the cathode ray diagram is a straight line. If the voltage increases beyond E_0 the diagram opens out with sides virtually parallel, indicating that some change has occurred in the atmosphere adjacent to the conductor. The air, has, of course, been broken down or completely ionized about the conductor radially outward as far as the voltage gradient of 76,000 volts per inch has been exceeded. Ions carrying charges of unlike sign to that of the conductor move in quickly to its surface and are discharged. Those carrying charges of like sign are repelled and move quickly to the boundary stated above, whereat the electric intensity has fallen to the critical value of 76,000 volts per inch. Thereafter their velocities are far lower, so much so that their positions remain in effect much the same until a reversal of the action occurs by a corresponding reversal of the voltage crest from E to $-E$.

Fig. 3 illustrates the state of things in the electric field about a conductor due to corona formation when the voltage has just passed through the crest value E, and is near the value of E_0, diminishing. The electric field attached to the conductor was set up by the critical value of voltage, E_0. The rest of the field due to the increase of E above E_0 was terminated upon the ions that were lodged just beyond the envelope of ionized atmosphere as specified. It follows that the electric intensity adjacent to a high-voltage conductor in the air cannot exceed critical value. Another view of the same fact is that ionized air functions as a conducting envelope about the conductor through which the fall of potential produced by charging current must be near zero.

The value of the field thus detached from the conductor is $Q_c - Q_b$ in Fig. 2. Having been carried into place by ions it cannot be removed by the ordinary action of a displacement current through the charged dielectric to the electrode conductor. Such ion-attached field will persist until discharged by ions of unlike sign repelled from the conductor when the succeeding negative crest value of the voltage occurs. The energy in the ion-attached field cannot, therefore, be returned to source through the conductor. Such field can only be reduced to zero by degrading the energy stored in it to heat.

Fig. 4 illustrates the same corresponding state of things when the value of the voltage is near $-E_0$, increasing. The field attached to the ions now terminates on the conductor, and no longer on the neutral

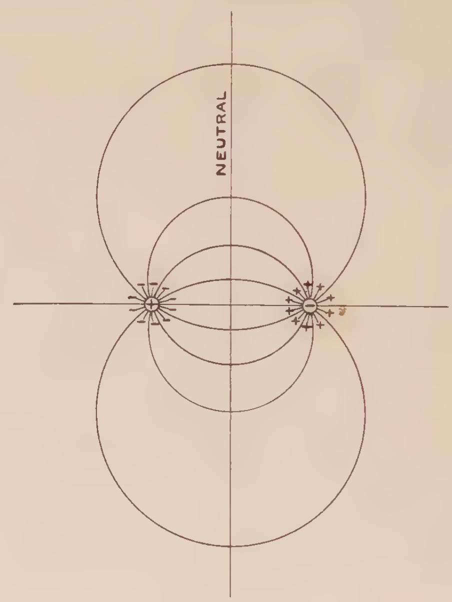

Fig. 4

surface. Thus it becomes understood that whereas the charge set up by the voltage, E_0, from conductor to neutral is Q_a without corona formation; with corona formation and E diminishing from E_0 it must have a value *larger* than Q_a by the amount of the field attached to the ions, *i. e.*,

$$Q_a = (E - E_0)\,C = Q_c - Q_b;$$

Likewise, with corona formation and E increasing toward E_0 it must have a value *smaller* than Q_a by this same amount of the field attached to the ions.

Thus it is that the chief factor in corona formation

is the production of a hysteresis relation of voltage to charge. The charge lags behind the voltage a definite amount throughout the cycle. For any given value of the critical voltage, E_0, the energy thus lost in corona hysteresis per cycle is dependent only upon the crest value of the voltage, E. In the voltage-corona loss relation, therefore, the value of the crest voltage is of dominating importance. The root-mean-square value of the voltage, as such, has no relation to the magnitude of the energy lost in corona per cycle.

Critical and crest voltages to neutral, capacitance to neutral and frequency have thus been found to be the primary controlling factors in corona formation. The value of the critical voltage, E_0, has long since been known to be dependent upon a number of secondary factors. Of these the *irregularity factor* is at once the most important and difficult to manage.

Irregularity factor is the ratio of the average to the maximum intensity of the electric field adjacent to the high-voltage conductor. The value of this ratio is dependent upon other related factors such as the mechanical, physical and chemical irregularities of the conductor surface, the magnitude of the supply of free ions in the air about the high-voltage conductor and the manner and extent to which such free ions are associated with moisture, dust particles or with other finely divided matter.

Critical voltage has a crest value that is just sufficient to produce break-down or ionization in the air adjacent to a high-voltage conductor. When the corresponding electric field is attached to the conductor with uniform density, the value of the critical voltage is maximum. When, from some cause, the density of the electric field is irregular, the corresponding value of the critical voltage is given by the product of the values of the maximum critical voltage and the irregularity factor.

These third-order factors may be absent to such an extent as to raise the irregularity factor to unity. In that event full corona will be found to occur near to and above the critical voltage. No isolated brushes will have been formed. Or these third-order factors may be present to such an extent that the resulting irregularity factor may have been forced to a very low value, 0.5, more or less.

At the corresponding critical voltage a few stray brushes are formed. As the voltage is raised, the number of brushes is increased. Through their mutual shielding effect the irregularity factor is also raised. This action continues with increase in voltage until a point is reached whereat no space is left in which to accommodate more brushes. Thereafter the brush pattern is fixed and so are the irregularity factor and critical voltage constituting the condition of full corona formation.

From these considerations it was evident further progress in the studies required that the voltage-charge relation should be understood for brushes occurring singly or in multiple, as well as for full corona formation.

To study the voltage-charge relation for single brush discharges the set-up diagrammed in Fig. 5 was used. Large metal screens were set in vertical planes about two feet apart and grounded. The cathode ray tube was placed between the screens. The 36-inch sphere was placed about three feet from the screen on one side, and the point which was the source of a brush discharge was placed about 30 inches from the other screen. It was connected to the wattmeter as shown. Its height above the concrete floor was about four feet. The potential reducing plate used on each side was insulated from the large screen by a layer of beeswax. One deflector plate of each pair in the cathode ray tube was grounded, and the others were connected to the potential plates. Grounded shield plates partly covered the potential reducing plates for adjusting the amount of the deflection of the cathode ray beam along each axis so as to obtain a card of suitable dimensions.

The 36-inch sphere was used to produce the voltage deflection. Since there was no corona on it, the electric field set up was proportional to and in phase with the voltage, and the potential reduction plate gave a certain

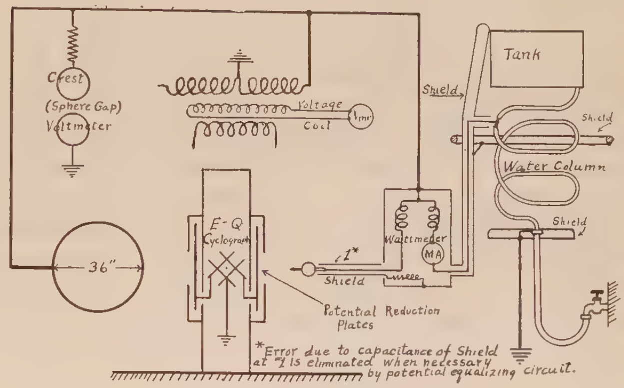

FIG. 5

percentage of the voltage between the sphere and ground. The point produced a good supply of ions on the other side even at relatively low voltages. Hence, the potential reduction plate on that side produced a deflection proportional only to the electric field or charge and not to the applied voltage. The appearance of the apparatus is shown in Figs. 6 and 7.

The point was connected to the source through the wattmeter[2] shown in the diagram whereby the powers consumed in the brush formed from the point at various voltages could be observed. The diagrams obtained at 20, 30, 50 and 80 kilovolts to ground are designated as A, B, C and D, respectively, in Fig. 8. The following table gives a summary of the results obtained.

Kilovolts to Ground	Watts by Wattmeter	Areas of Diagrams sq. in.	Ratios Watts/Areas
20	0.0	0.00	..
30	0.8	0.06	13.3
50	3.1	0.26	11.9
80	11.3	1.10	10.3

2. A description of this wattmeter has been given by Carroll, Peterson and Stray in a paper entitled Power Measurements at High Voltages and Low Power Factors prepared for the October, 1924, Pasadena Convention of the A. I. E. E.

Because the deflections of the cathode ray were not exactly proportional to the actuating potentials, it follows that it was not proper to expect equality in the ratios of the areas and their corresponding powers observed by wattmeter. The fact, however, that the ratios did not differ greatly shows that the diagrams are good indications of the nature of the mechanism of the corona loss occurring in brush discharges.

Looking at the corona-brush diagrams critically one learns that their hysteresis character remains complete without mutilation until the value of the

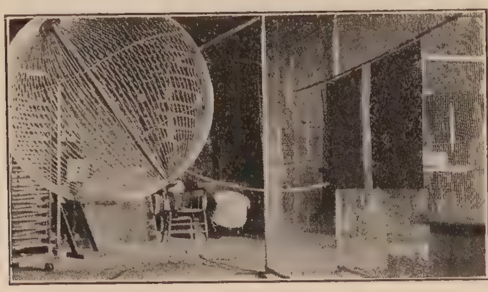

Fig. 6

applied voltage is more than double the critical voltage at which the brush was started. Finally, as the voltage was raised the length of the brush became too great for all of the ions to reach their boundaries promptly. The space within the brush remained occupied to some extent with ions of both signs. Hereby gas conduction developed as it is ordinarily understood. A compound diagram resulted due to the combination of two, one because of hysteresis and the other resistance. The form of the one is obliquely rectangular and of the other eliptical.

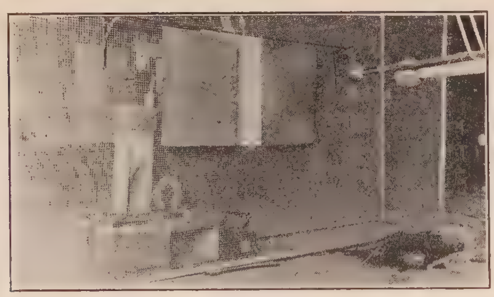

Fig. 7

For the study of corona brushes in multiple, brush patterns on cylindrical conductors were produced artificially by means of short tacks or water drops placed at regular intervals.[3]

The heads of the tacks were cemented to the surface of the conductors. The high-voltage wattmeter was used to determine the corona loss-voltage relations. The conductor length was 5 feet; diameter 0.532 inch; and the surface was studded with tacks ¼ inch long. The corresponding areas of conductor surface per tack, critical voltages, applied voltages, losses and values of x in $P = k\,(e - e_0)^x$ at e are given in the following table:

Square Inches per Tack	e_0 Critical Voltage Kv.	e Applied Voltage Kv.	Loss Watts	x in $P = k\,(e - e_0)^x$ at e
0.0625	40	90	50.5	1.56
0.25	40	90	50.5	1.56
1.00	40	90	50.5	1.56
1.64	43	93	44.5	1.64

From these results it is clear that the full corona loss-voltage relation remains unchanged over a wide variation of the brush pattern. It is also clear why Peek and his co-workers who first studied this relation found it to be unchanged by the degree of free ionization present in the air about the high-voltage corona-forming conductors.

As the value of the critical voltage rises from any

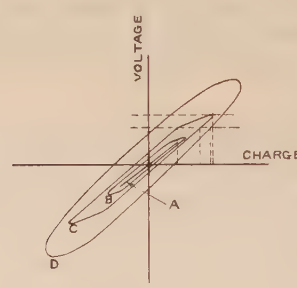

Fig. 8

or all of several causes specified above, local corona by brush formation diminishes and practically disappears when its maximum value has been attained. The corresponding loss-voltage curves obtained by measurement straighten out with rising critical voltage. Thus the difference between Peek's law of corona for a given frequency

$$P = k\,(e - e_0)^2 \text{ and}$$

equation (2)

$$P = 4\,f\,C\,(E^2 - E\,E_0) \text{ is}$$

of little value. The essential difference is in the values of e_0 and $0.707\,E_0$. Each must be obtained by substituting the same observed values of P and applied voltages, e, and $0.707\,E$ in their respective equations. The cause of the difference will be apparent when the two methods of attack have been recalled and compared. E_0 can be observed by the voltage-charge indicator and by calculation, while e_0 can be obtained only by calculation from the full corona loss-voltage relation. In the case of Curve 3, Fig. 9, these calculated values were found to be for e_0, 116 kv. and for $0.707\,E_0$, 133 kv.

The corona loss-voltage values given in the following

3. Carroll, Peterson and Stray, Power Measurements at High Voltages and Low Power Factors, October 1924, A. I. E. E. Pasadena Convention.

table were calculated by means of Peek's equation 34′ (High Voltage Engineering, 1920 ed.) for comparison with corresponding values that located Curves 3, 4, 5 and 6, Fig. 9.

CORONA LOSS
Kw. per Mile per Conductor

e Kv. to Neutral	Peek's Equation	$P = 4fC$ $(E^2 - E\,E_0)$ Curve 5	Curve 3	Curve 4	Curve 6
120	0.24	..	0.80	0.52	0.80
125	1.21	..	1.11	0.87	1.10
130	2.92	..	1.57	1.50	1.75
135	5.38	1.0	2.56	3.50	3.40
140	8.58	5.7	6.9	7.50	6.20
145	12.5	10.8	13.0	..	..
150	17.2	16.6	18.9	..	..
155	22.7	22.8	24.6	..	..

Thus in all ordinary circumstances corona forms from high-voltage conductors as an ionized gas hysteresis. So long as the accompanying brushes in full corona are not tall enough to change the capacitance of the conductor appreciably, the value of the power, P, as given by equation (**2**) should be substantially correct. When in effect the capacitance thereby is increased appreciably, the value of C in the equation must be augmented correspondingly to avoid error.

For comparison of the actual values occurring in the corona loss-voltage relation and the corresponding values calculated by equation (**2**), the authors are indebted to Messrs. J. C. Clark and Frank F. Evenson for the July and August 1923 data by which the curves numbered 1, 2, 3 and 7 were located in rectangular coordinates in Fig. 9. The coronas were formed on cables made up of 49-strand copper and rope-laid. The conductor diameters, single-phase center to center horizontal separations and meterological conditions are specified in the figure. By means of an improved high-voltage wattmeter curve No. 3 was relocated April 3 and again on April 5, 1924 and the corresponding results were charted also in the same Fig. 9. The corresponding curves thus located, but not drawn in, have been numbered 4 and 6. They were found to be in close agreement with Curve No. 3. Full corona formation is due to a brush pattern that, when once formed, remains fixed as long as the application of the 60-cycle voltage continues. The pattern is preserved throughout the cycle, although active ionization occurs only when the voltage exceeds the critical value. The foundation for the brush pattern is in the corresponding distribution of the ions that have been left isolated in the air immediately covering the conductor surface.

As the voltage is lowered, if the full corona brush pattern breaks up and local corona is formed, full corona critical voltage cannot be determined by voltmeter. It can only be determined from the voltage-charge diagram. Without such diagram it must be obtained by calculation from the observed full corona loss-voltage relation. This relation within fair limits is never complex. The corresponding equation can be derived with no difficulty. It may then be used to calculate the value of the critical voltage. In Curve No. 3, Fig. 9, the full corona part of the loss-voltage curve was found to be virtually a right line. The value of the corresponding critical voltage was found, therefore, by extending such line to the point where it inter-

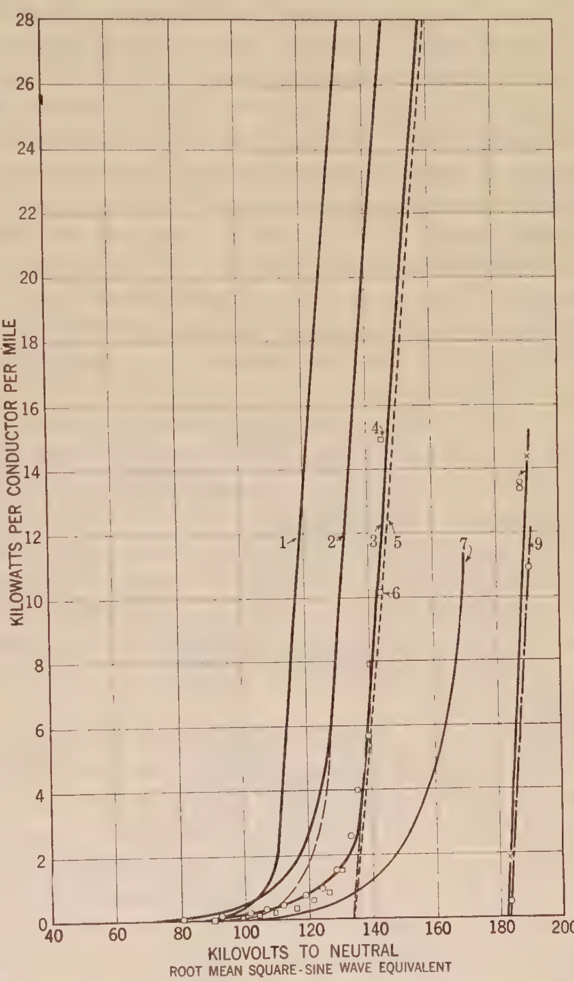

FIG. 9—CORONA LOSS

1. Rope Lay Copper 0.614 in. Dia.—Clark & Evenson.
2. " " " 0.80 " " " " "
3. " " " 0.91 " " " " "
   Aug. 2, 1923 — Clear; Windy.
   Barometer 30.01 in.
   Temperature 68 deg. fahr.
   Relative Humidity 52 per cent.
4. Rope Lay Copper 0.91 in. Dia., Carroll, Peterson & Stray.
   Apr. 5, 1924 — Clear; Light Breeze.
   Barometer 30.17 in.
   Temperature 68 deg. fahr.
   Relative Humidity 20 per cent.
5. Rope Lay Copper 0.91 in. Dia.
   Loss Computed from Equation
   $P = 4\,f\,C\,(E^2 - E\,E_0)$
   e_0 = 134 Kv. from Curve 3.
6. Rope Lay Copper 0.91 in. Dia., Carroll, Peterson & Stray.
   Apr. 3, 1924 — Cloudy.
   Barometer 30.05 in.
   Temperature 54 deg. fahr.
   Relative Humidity 51 per cent.
7. Rope Lay Copper 1.24 in. Dia., Clark & Evenson.
8. Concentric Strand Aluminum 0.952 in. Dia., Bright.
9. Ditto, Black.

Curves 8 and 9 plotted from results obtained on 6 ft. 19½ in. lengths in laboratory and corrected to basis of 17 ft. spacing.

Spacing: Curve 2 17 ft.
Curves 1, 3, 4, 5, 6, 7 18 ft.

sected the voltage axis, *viz.*, 134 kv. The capacitance to neutral per mile of conductor was 0.0145 μf. With these values by means of equation (**2**) Curve No. 5 was located in the same diagram, Fig. 9, and is in close agreement with Curve No. 3.

That the magnitude of the supply of free ions is a powerful factor in local corona formation may be understood through the results obtained in the following experiment: A bright, clean, 10-foot section of concentric strand aluminum-steel core cable, having a diameter of 0.96 inch, was mounted in the laboratory horizontally, 3 ft. 6.5 in. above the concrete floor neutral. It was connected through the wattmeter to the high-voltage source and properly shielded so that the only power values indicated by the wattmeter were those due to corona formation on the actual cable specimen. The corona loss-voltage values thus found were corrected to correspond to a distance to neutral of 8.5 ft. or 17 ft. between centers in a single-phase circuit. They were then used to locate Curve No. 8 in Fig. 9. The various active high-voltage leads and terminals present in the indoor laboratory drained the space of free ions to such an extent that the formation of an appreciable brush pattern was prevented, resulting in the absence of local corona formation. Full corona formed at an increment of voltage above the maximum critical voltage. Without correcting for the shielding effect due to the proximity of the high-voltage connecting leads the calculated value of the irregularity factor exceeded unity.

After aluminum cables of the sort just specified have been in service with corona formation, they will, in some circumstances, become coated with a definite layer of finely divided carbon, dust particles and cementing material causing the coating to adhere firmly. Through the understanding of corona formation herein presented it appeared reasonable to expect that the corona loss from the roughened carbon-coated specimen should be less at a given voltage than from the bright, smooth and clean specimen of what would otherwise be the same cable. The film of oxide covering the bright cable would thus inevitably interfere a little with the ready access of the incoming ions to the raw surface of the conductor. It would interfere to a degree with the uniformity of distribution of the ions moving toward and away from the conductor. On the other hand, the incoming ions for the carbon-coated cable would strike everywhere a conducting surface that should facilitate the development of full corona with a more nearly complete absence of brush formation with a corresponding increase of irregularity factor and of critical voltage. The test was, therefore, made for the black cable and the corresponding results were used to locate Curve No. 9 in Fig. 9. From these curves it was found that at 190 kv. the losses per conductor-mile for the bright and black cables were respectively 13.3 and 10.2 kilowatts.

For 10 years it has been known that 60-cycle discharges are routed substantially over the shortest paths between opposing high-voltage electrodes and that in contradistinction thereto radio frequency discharges occur over the routes of the tubes of force established by the impressed voltage.[4,5] The hysteresis character of 60-cycle brushes leads to an understanding of the cause of the difference in the routing of these two forms of discharge. At 60 cycles there is ample time for ions carrying charges unlike those attached to the high-voltage conductor to move up to it and be discharged; and for the ions of like charges to be repelled from the conductor and to reach their boundaries just beyond the ionized zone of air covering the conductor. Such surviving ions are drawn in a direct route to the opposing electrode by the tension of the electric fields attached from them to it. In the radio frequency discharges the state of things is quite different. The time between voltage crests is too short for the segregation of the ions to any considerable extent. The result is that the brushes which become discharges are occupied with ions of both signs. Their fields cancel and they are propelled only in the direction of the original fields, due to the source voltage applied between the electrodes.

Conclusions

1. Sixty-cycle corona in all ordinary circumstances develops the character of a gas dielectric hysteresis.

2. The values of *crest voltages* are controlling in respect to losses by corona formation.

3. *Critical voltage* can have a definite value only when the brush discharge pattern in corona formation is stable. Its value should be understood to be given by the product of the maximum critical voltage and the irregularity factor.

4. *Irregularity factor* should be understood to be the ratio of the average to the maximum electric intensity of the field adjacent to the high-voltage conductor.

5. The rational corona loss-voltage relation is given correctly by equation (**2**) only within those limits of full corona formation wherein the capacitance value and brush pattern remain fixed.

6. Local corona loss varying from 0 to 8 kw. per mile depends upon too many variable factors to permit of calculation without the use of knowledge to be obtained only through a large amount of further study by measurements.

7. The strong ion-formed fields that are responsible for the corona hysteresis are the cause that routes a 60-cycle discharge by the shortest path between electrodes. Without such fields, as in radio frequency discharges, the discharge routes must be along the tubes of force of the original electric fields.

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4. Harris J. Ryan and Roland G. Marx, Sustained Radio Frequency High Voltage Discharges, *Proc.* Inst. Radio Engineers, Vol. 3, p. 359, Fig. 7, December, 1915.

5. Harris J. Ryan, H. H. Henline, F. F. Evenson, Flashover of Insulators, *Electrical World*, Vol. 78, p. 563, Fig. 4, September 17, 1921.

Electricity's Contribution to the Steel Industry

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Review af the Subject.*—A brief outline of the processes involved in the production of steel is followed by a discussion of the characteristics of the various rolling mills and the types of motors used to drive them. Considerations affecting the choice of frequency are also discussed. The author believes that the greatest contribution of electricity to the steel industry is the providing of a means for economically using the waste gases from blast furnaces. He points out the importance, as a conservation measure, of the utilization of blast furnace gas and other sources of by-product power.*

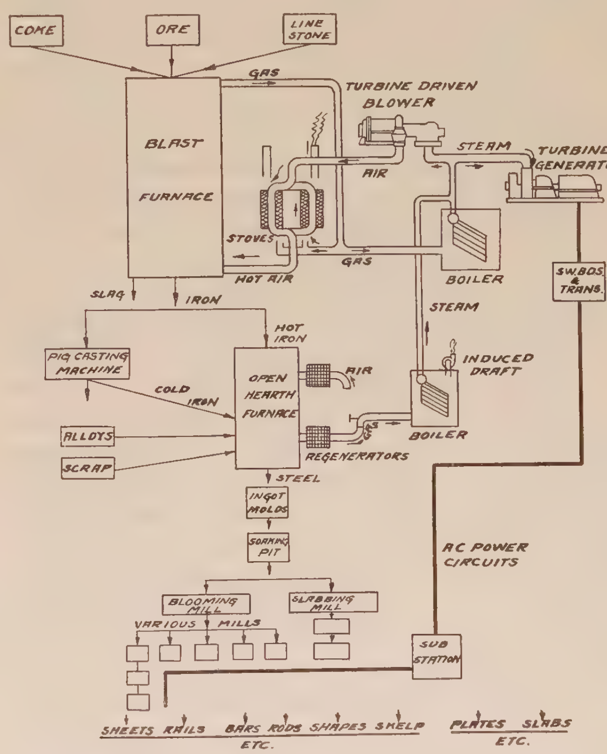
* * * * *

THERE is no industry which offers greater opportunities for saving by the application of electric power or which presents a greater variety of complex engineering problems in connection with its use than does the steel industry. Sufficient potential energy is available in the form of waste gases and of waste heat for the development of all, or a large part, of the power required in many of the plants for not only producing the steel but for rolling it into finished shapes, such as rails, plates, merchant bars, etc.

Nowhere do we find motors applied where the conditions to be met are more severe. The slogan of the steel plant is "tonnage and more tonnage" and the electrical equipment must be designed to fit into a program which is made up of record productions. The fluctuations in load are rapid and extreme and the mechanical strains to which the equipment is subjected are so severe, under normal conditions, that unusual precautions must be taken to prevent injury to the mechanical parts. The motor bearing pedestals are made massive and of only sufficient height above the base to allow space for the oil well, in order to make them strong enough to withstand the side thrusts incident to the steel rolling cycle. The rotor spiders are usually steel castings and the windings are specially braced and bound to prevent injury from the severe shocks as the steel enters the rolls. Accessibility, interchangeability and ease of repair are permanent requirements to be met by the motor and control designers. For driving the auxiliaries, such as roll and transfer tables, screw downs, manipulators, cranes, etc., it has been found necessary to develop a special line of totally enclosed d-c. motors of a very heavy mechanical construction throughout and with armatures having low moments of inertia to permit of quick reversal, the ordinary types of motors, including railway motors, having failed completely in steel mill service.

For the assistance of those who are not familiar with the production of steel, a brief outline of the several steps involved is given:

Ore (oxides of iron), limestone and coke are brought together in the blast furnace where the oxygen is removed by the coke and many of the impurities are carried away by the limestone in the slag. The amount of coke required, of course, depends upon the ore, but a fair average is about one ton of coke per ton of pig iron produced. From the blast furnace, the molten iron is drawn off and either cast into pigs or is taken in the molten state to the open hearth or bessemer furnaces where the excess carbon and other impurities are removed. From the refining furnace, the steel is cast into ingots, the cross section and weight of which depend upon the section into which it is to be rolled in the mill, standard ingots varying from approximately



FLOW DIAGRAM OF STEEL MILL
SHOWING UTILIZATION OF GASES FOR POWER PURPOSES.

Fig. 1

10 in. by 15 in. by 64 in., weighing 1850 lbs., to 30 in. by 64 in. by 84 in., weighing 41,000 lbs. When the ingots have cooled sufficiently to permit of their being drawn from the mold, they are either set aside for stock or carried immediately to the soaking pits, which are merely gas fired furnaces in which the ingots are placed until they reach a uniform temperature which makes them suitable for rolling. From the soaking pits they go immediately to the rolling mill, generally a blooming

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mill or a slabbing mill, where they are reduced either to an approximately square section in the former or to a rectangular section in the latter. The size of the blooms or billets, as they are called, varies usually from 8 in. by 8 in. a standard rail bloom, to 4 in. by 4 in. a standard merchant billet. Slabs vary between much wider limits, ranging from 46 in. by 12 in. and 52 in. by 6 in. to 12 in. by 2 in.

From the blooming mill, the steel goes to the various roughing and finishing mills and is rolled into rails, structural shapes, merchant bar, concrete reinforcing bar, strip, sheet bar, skelp for tubes, etc., the sheet bar being reduced to sheets in sheet mills.

The steel from the slabbing mill is usually rolled into plates either in a universal or sheared plate mill.

Each of the mills has special characteristics which affect the choice of the electrical equipment required to drive it. Blooming mills may be either of the reversing (reversing each time the steel passes between the rolls) or non-reversing type, depending upon whether they are operated more or less independently of other mills or form an integral part of a continuous mill. In the latter case, while they are usually non-reversing, they are not necessarily so. The speed at which the rolls will grip the steel in entering is determined by their diameter, the cross section of the steel and the reduction in area so that, especially for the earlier passes, the rolls must be slowed down to 15 or 20 per cent of their maximum rolling speed until the steel has entered, and then the motor and mill is accelerated against the load. Such mills, in order to obtain reasonable efficiency are, therefore, driven by d-c. motors with combined Ward-Leonard and motor field control. In many of these mills an average of not more than five seconds is allowed for a complete pass, including time required to accelerate, roll at full speed, retard and get the steel back to the rolls ready to reenter, making it necessary to take extreme measures to obtain the maximum rates of acceleration and retardation. To meet this condition, the time constant of the fields of the generators supplying the direct current for the roll motors is decreased by the introduction of external resistance, the inertia of the motor armatures is reduced to a minimum, and the control is designed to limit the power during acceleration only to that at which the machines will satisfactorily commutate.

The following performance of a large reversing motor under actual operating conditions will be of interest as indicating the completeness with which these details have been worked out.

At the Trumbull Steel Plant a 6500-h. p. (continuous rated 50 deg. cent.) double armature reversing motor approximately 12 ft. in diameter at the gap with an armature and shaft weighing 242,000 lbs. has rolled 60 ingots, requiring 13 passes each, making a total of 780 passes in an hour, an average of 4.6 seconds per pass, and has been reversed light from 45 rev. per min. in one direction to 45 rev. per min. in the other in 0.8 sec. Yet one of these motors is so completely under the control of the operator that its armature can be jogged an inch or two at a time or rocked back and forth at will.

Where the blooming mill is non-reversing, it can be, and usually is, driven by a constant speed induction motor.

A slabbing mill differs from a blooming mill in having both horizontal and vertical rolls which may either be driven independently by separate motors or geared together and driven by a single unit. In the former case, special precautions must be taken in the control of the driving motors to insure a proper distribution of the load but, in the latter case, the standard blooming mill drive suffices.

The blooms or billets from the reversing mill are cut into lengths, depending upon their use, and either sent to the stock pile or, in the case of large rail or structural mills, they may pass directly to the roughing and finishing mills, either with or without re-heating, where they are rolled into their final form. Such roughing and finishing mills usually consist of a large number of stands, either geared together and driven by a single motor or driven as units or in small groups from a number of independent motors, which, in either case, are non-reversing.

Although much has been said in recent years about the specialization of the product from large continuous mills (and many mills are designed with this in view) it is still true that a considerable variety of sections is rolled in by far the greater majority of these mills. The speed at which a given section can be rolled depends upon a number of factors and there is a critical speed for each section which gives the maximum economy, so that, obviously, if a mill rolling a variety of product is to be operated at maximum productive efficiency, the speed of all or of a part of its stands must be varied over a considerable range. D-c. motors might have been used to obtain the required speed control to give maximum efficiency, but the advantages of a-c. induction motors were so thoroughly appreciated by steel mill operators that at first attempts were made to operate the mills at compromise speeds by driving the rolls with multi-speed changeable pole or concatenated induction motors. Although the production of the mill, both as to quantity and section, was taken into consideration in choosing the compromise speeds, the mill productive efficiency fell far below the ideal.

Appreciating the advantages of the induction motor for rolling mill service, engineers both here and abroad bent their efforts to finding a means of obtaining speed characteristics with the induction motor similar to those of the adjustable speed d-c. shunt motor and, as a result, several systems of control were suggested, but of these only two have found their way into the steel mill to any considerable extent. These are commonly

known as the Scherbius and Kraemer Systems and the extent to which each has been used is indicated in the following table:

TABLE I

	60 and 50 Cycle		25 Cycle		Total	
	No.	H. P.	No.	H. P.		
Scherbius	21	34,090	42	57,290	63	91,380
Kraemer	34	38,350	10	14,450	44	52,800
Freq. Conv	2	1,000	1	800	3	1,800
Total—All Kinds	57	73,440	53	72,540	110	145,980

Time will not permit of a complete description of of these systems in this paper but if the reader is unfamiliar with them he will find them outlined in a paper "Some Methods of Obtaining Adjustable Speed with Electrically Driven Mills" which was read by the writer before the Engineers' Society of Western Pennsylvania in 1921 or in numerous papers which have been read before the A. I. E. E., Association of Iron & Steel Electrical Engineers and published in the technical press.

These two systems are affected differently in their characteristics by the frequency of the supply system, the range of speed control and the character of the load cycle; and the choice between the two types should be made only after giving all the factors involved most careful consideration.

The requirements imposed by range and refinement of speed control have constantly increased until today, (in spite of the many advantages of the induction motor over the d-c. motor as a main roll drive) it has become necessary to resort to d-c. machines to meet these new conditions and a number of large d-c. motors has been purchased recently. These motors are either in operation or in process of manufacture and the indications are that they will be used to a still greater extent in the future. Paralleling the development of a-c. adjustable speed equipment, the d-c. motor has been greatly improved through the use of commutating poles and compensating windings and these installations are operating with entire success.

Constant speed induction motors are used for driving the single-stand non-reversing mills that are used for rolling into plates the product of the slabbing mills.

As far as we are able to determine from the records, the first installation of a motor in a rolling mill was made in the works of the Pencoyd Steel Company near Philadelphia about 1889 and consisted of a small motor driving a traveling crane; and up to October, 1905, the application of electric motors in steel plants in America was confined to relatively small motors driving the mill tables, cranes, etc., although a number of notable installations of main roll motors had been made in Europe.

The first main roll drive of importance in America was installed at the Edgar Thompson Works of the Carnegie Steel Company in October, 1905, while in 1919 the Fourteenth Census gives 2,350,596 h. p. as the primary horse power in electrical equipment in the steel industry and today this has probably increased to approximately 3,000,000 h. p.

A very interesting fact is disclosed by the following figures, taken from the Fourteenth U. S. Census:—

TABLE II

	Total Primary Horse power*	Total Electric Primary Horse power—Owned and Rented	Per Cent
1904	1,649,299	254,258	15.4
1909	2,100,978	716,609	34
1914	2,706,553	1,207,715	44.5
1919	3,820,917	2,350,596	61.5

*Steam, electric, internal combustion and water power.

	Growth in Total Primary Horse power—Steam and Electric	Growth in Primary Horse power Electrified
1904-1909	451,672	462,351
1909-1914	1,057,254	953,457
1914-1919	2,171,618	2,096,338

Referring to Table II, it will be seen that the growth in electric power in the steel industry is substantially equal to the increase in total primary horse power since the first application of electric power to the main rolls. It is true that some steam engines have been installed in rolling mills during this period but an equivalent capacity has been replaced by motors.

The growth in primary horse power which is electrified at blast furnaces, which are treated separately from steel works and rolling mills in the Census Report, has also been very rapid, increasing from 52,610 h. p. in 1904 to 242,554 h. p. in 1919. While this represents only approximately 30 per cent of the total growth in primary power in blast furnaces, it is as large as we would expect it to be, as a large part of the power required in the operation of a blast furnace is consumed in compressing the air for the blast and, with the waste gases from the furnace close at hand, the maximum economy can be obtained by driving the blowers by gas engines or by steam turbines supplied from gas-fired boilers, the latter representing the most modern practise.

As is also disclosed in the Fourteenth Census, there has been a very marked growth in the amount of power purchased by steel companies from Public Utilities. Power thus acquired has increased from approximately 59,000 h. p. or 2.8 per cent in 1909 to approximately 695,000 h. p. or 18.2 per cent of the total primary horse power in 1919. This growth is, of course, largely confined to those plants which do not operate blast furnaces in conjunction with their rolling mills but not wholly so, as a number of our largest steel companies is purchasing large blocks of power from the Utilities.

Frequency of 25 cycles was adopted by the large steel companies for their early installations, principally be-

cause at 60 cycles the very low speed at which the rolling mills operate necessitated an extremely expensive induction motor having low power factor. The difficulties encountered in paralleling large 60-cycle generating units driven by gas engines were also a factor. The question as to whether steel mills could be successfully driven by 60-cycle power naturally arose among steel mill engineers when later considering the purchase of power from the Utilities. Although I believe it is quite generally accepted that steel mill conditions can be met with entire success by 60-cycle service, a brief discussion of this very important point may be worth-while.

From the standpoint of production, both as to quantity and quality, steel can be successfuly rolled by either 25-cycle or 60-cycle power, and the question as to which frequency should be used in the electrification of any plant is one which must be answered by the executives of the interested company, acting under the advice of their engineers, since some of the vital factors affecting the choice are of such a nature that their importance cannot be properly appraised from without. A determining factor in the case of one plant may be worthy of only minor consideration in another, although this may not be at all apparent without knowledge of facts possessed only by the executives of the steel company.

There are, however, certain rather clearly defined advantages which apparatus, designed to operate at one frequency, possesses over that for the other, and a very brief review of these advantages may be of assistance in a preliminary study, although final conclusions should be based on a careful analysis of the exact conditions obtaining in each case.

Generating and transforming equipment, including motor generators and synchronous converters, for supplying power for the d-c. auxiliaries are less expensive per kw. or kv-a. at 60 cycles. For alternating current general purpose motors, 60 cycles makes possible a greater number of speeds within a given range, although no serious inconvenience has resulted from the limited number of speeds available where 25 cycles has been adopted. Sixty-cycle general purpose motors are also slightly cheaper, but the total cost of these units is only a small item in the total cost of the electrical equipment in a normal steel plant. In fact, except for the main roll motors, 60-cycle equipment seems to have the advantage in the first cost.

Whether or not constant speed main roll motors are cheaper for 60 cycles or 25 cycles, depends upon their capacities and speeds. For large direct-connected motors, 60-cycle equipments are much more expensive than the corresponding 25-cycle units, and their power factors are very much lower, resulting in a higher cost of power whether purchased or generated locally. It is true that the power factor of low-speed 60-cycle motors can be raised to equal that of 25-cycle units by the addition of synchronous condensers, but unless these are placed near the motors, the cost of the transforming and transmitting equipment between the generating station and the motors will not be reduced by their use. Due allowance for this and for the cost of the synchronous condensers, wherever located, must be made in the cost of the 60-cycle installation.

The use of high-speed 60-cycle motors geared to the mills, together with the gears, gives costs slightly below those for the 25-cycle direct-connected units, but the operating handicap of the gears must not be lost sight of. The 60-cycle smaller moderate-speed main roll motors are, in general, slightly lower in cost than those for 25 cycles.

Adjustable-speed a-c. main roll motors may be made for either frequency, and like the constant speed units in general the costs are affected by speed and frequency.

We have analyzed the conditions obtaining in several large steel plants, from which the following conclusions are deduced, which conclusions, I believe, will apply in general to large and moderately large plants.

If power is generated locally and the large main roll motors are direct connected, the capital cost of the 60-cycle installation as a whole will be 10 to 15 per cent greater than that for the 25-cycle installation; and if power is purchased, this difference, not including the power plant, may be doubled although, of course, the cost of generating equipment will be saved. The efficiency, which I have purposely refrained from discussing in detail because of its dependence upon so many factors such as power factor, gearing, etc., will for both frequencies be practically the same for the plant as a whole.

Based upon the facts revealed by our detailed study of these plants, I feel justified in making the following general recommendations:

Whether or not it is intended at a later date to generate power locally, where power can be purchased at an attractive rate and where there are no reasons, apart from the question of frequency, for not purchasing it, power should be purchased and the equipment designed, of course, for the frequency of the power supplied, which will be almost universally 60 cycles.

If power is to be generated locally, the overall first cost of the electrical equipment will be less for 25 cycles, but the decision to adopt this frequency should not be made until due consideration has been given to the advantage of tying-in with the Public Utility supplying the district.

Two vital factors which determine whether the power is to be purchased or generated are:

First. The importance of making the plant self-contained, and

Second. The return, if utilized for development along other lines, which may be realized on the money required to build the local generating plant.

Obviously, the weight of these factors must be determined by the plant executives as previously suggested. If blast furnace gas or by-product fuels

from any other source are available, conservation demands their utilization which can, in general, best be accomplished through the generation of electric power locally.

I have assumed that the choice of frequency is not hampered by an existing development. Obviously, the inertia of a partial electrification along one line may be such as to make it necessary to proceed along this line, although a different course could advantageously be pursued if not hampered by an existing installation.

The extent to which 25 and 60-cycle equipment is used in steel mills is indicated by the following figures, which give the approximate number and capacities of the main roll motors 300 h. p. and larger of the several frequencies, supplied by the three principal manufacturers up to July 1923.

TABLE III

Frequency	Number of Motors	Total Horse power
25 cycles	329	472,915
30 "	1	1,500
40 "	9	4,850
50 "	37	54,100
60 "	423	416,735

Earlier in the paper, figures have been given which indicate that from the time the first rolling mills were driven by electric power, the growth in electrified primary horse power has been equal to the increase in total primary horse power. This, in itself, is sufficient evidence that electricity has made a material contribution to the steel industry.

While the advantages of electric drive were fully appreciated almost immediately by the mill operator and engineer, they are perhaps not generally understood by those not specializing in this field, although, fundamentally, they do not differ materially from the advantages accruing from electrification in other industries.

The uniform torque of the electric motor throughout the entire revolution of its armature and its close speed regulation over wide ranges of load are ideal characteristics for a main roll drive, especially for adjustable speed and reversing mills.

As previously stated, for each section and draft there is a critical roll speed above which, if they will bite at all, delays are experienced in entering the steel in the rolls. In order to obtain this low entering speed in engine-driven reversing mills, the valve is merely "cracked" so that when the steel actually enters the rolls, time is required for the operator to open the valve and for the cylinders to fill with steam. This delay allows the engine to slow down and frequently it comes to a dead stop. Also, in spite of the fact that the operators are extremely skillful in handling their engines, as the steel leaves the rolls the cylinders are frequently full of steam causing the racing so characteristic of steam-driven mills. On the other hand, as the motor in the electrically driven mill slows down, its torque instantly increases and the speed only drops slightly as the steel enters and merely returns to the entering speed when the steel passes out. These same tendencies are present in the non-reversing mills but to a less degree.

We would expect, as a result of these characteristics of the steam engine, reduced production for the same maximum rolling speed and very greatly increased maintenance cost and delays for making repairs both to the engine and mill as compared with the electric drive. An investigation of the subject reveals ample confirmatory evidence of the low maintenance cost with the electric drive. As typical of many reports received, one large steel operator records a negligible maintenance cost for his reversing blooming mill, which has been in operation over six years, and also for his finishing mills, which are of the adjustable speed Scherbius type.

The ability to accurately measure, not only the total power consumed by a mill over an extended period, but to analyze the power of each pass, has made it possible to study every detail of the power requirements for rolling steel. With these data at hand, the engineer can effect otherwise impossible savings in the first cost of his mill installation by more accurately proportioning the capacity of his motors to the mill requirements; and he can so design his rolls as to distribute the work more advantageously throughout the several passes without danger of detrimentally affecting production, a practise which is actually being followed.

Better illumination and better working conditions are, as in other industries, important contributions of electricity to the steel industry and the application of electric power to many of the auxiliaries is so commonplace that we seldom appreciate how difficult it would be to operate a modern steel mill without the electric motor. Take for example, the large overhead cranes, it is difficult to conceive of operating them with the freedom and safety of the modern equipment, if at all, without electric power.

It is difficult to determine what has been the greatest contribution of electricity to the steel industry because those factors, such as improved lighting, reductions in delays, etc., which affect production are not always readily capitalized, and frequently are not fully appreciated. In general, however, I believe that providing a means for economically utilizing the waste gases from the blast furnaces will be generally conceded to be electricity's greatest contribution to the steel industry.

As a result of the chemical reactions which take place in the blast furnace, there is produced a combustible gas which varies in volume and in thermal value, depending upon the coke ratio; that is, the weight of coke per ton of pig iron produced.

The relationship between coke consumption, volume of gas and thermal value of gas in terms of pig iron produced is very conveniently shown by curve Fig. 2

included by H. A. Brassert in a paper which he read before the American Iron and Steel Institute and which, with his permission, I have reproduced.

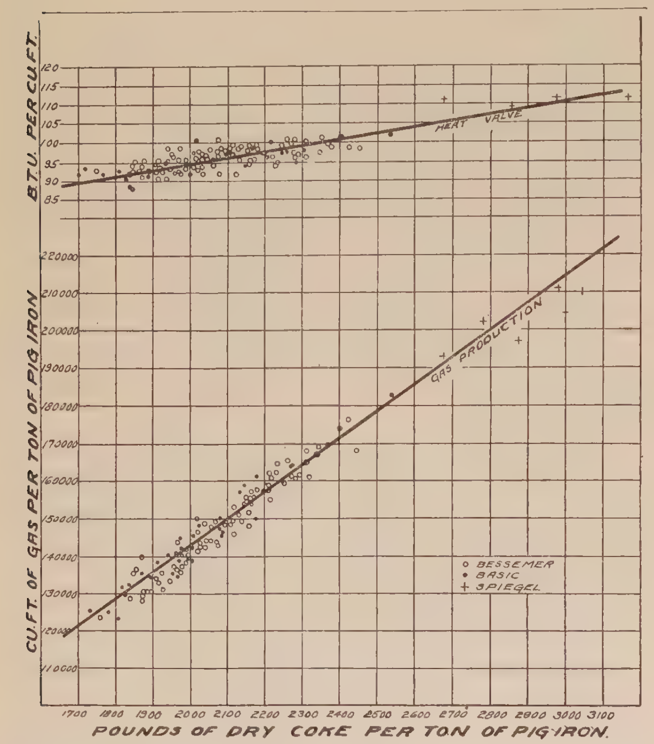

Fig. 2—Effect of Coke Rate on Production of Blast Furnace Gas

It will be seen, from these curves, that the gas per ton of pig iron varies from 128,000 cu. ft. to 157,000 cu. ft. and that its heat value varies from 92-B. t. u. to 98-B. t. u. per cubic foot as the coke charge varies from 1800 lb. to 2200 lb.

A part of the potential energy of the waste gases is required to operate the blowing engines and other blast furnace auxiliaries. The percentage of gas required by the blast furnace auxiliaries is variously estimated by the several authorities, but the differences are not of importance to us and are due probably to variations in the coke charge necessitated by lack of uniformity in the character of the ore.

Hubert Hermanns in an article "Blast Furnace Waste Heat Utilized," which appeared in the October, 1922 issue of The Blast Furnace and Steel Plant, included a very clear sketch showing the energy balance of a blast furnace, which I am reproducing, with slight modification, with his permission. His percentages are based on the potential energy of the coke charge, which is taken as 100 per cent. The most common practise in dealing with the subject of waste gases is to base the percentages on the waste gas discharged from the furnace assumed at 100 per cent. Therefore, to make these figures correspond with the usual practise, they should be increased by the ratio $\frac{100}{60} = 1.67$, from which it follows that the excess gas available for the

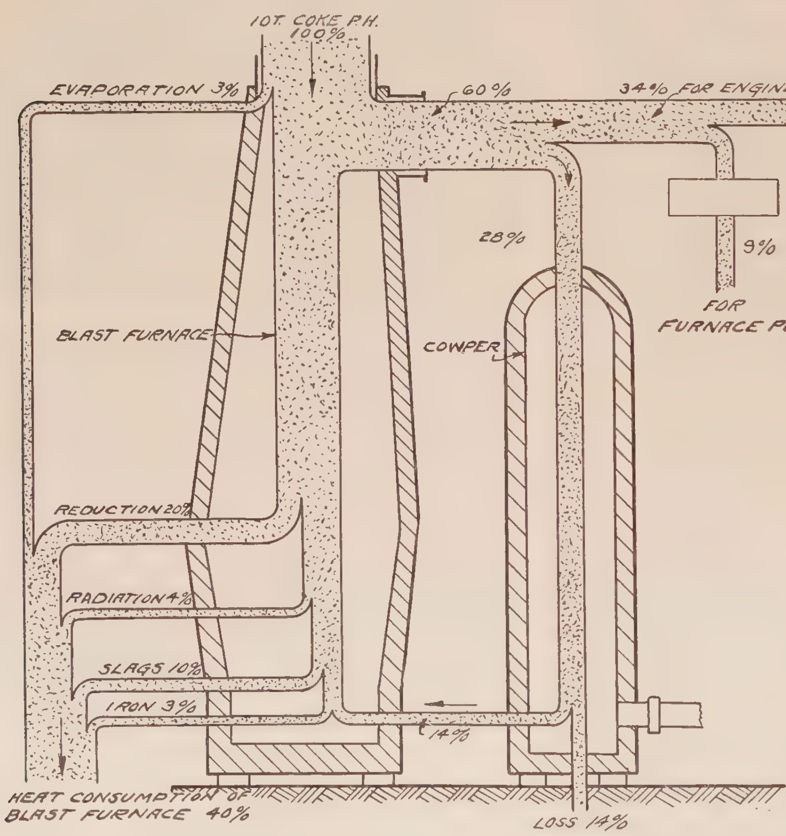

Fig. 3

generation of power for general use in the mill is 38½ per cent of that discharged from the stack.

When rolling mills are operated in conjunction with the blast furnaces, the modern practise is to convert this excess energy into electric power for use throughout the mill. Where the blast furnaces are isolated, little, if any, progress has been made toward the utilization of this energy, even where conditions appear at first sight to be most ideal for doing so. I have in mind a district which produces a large volume of pig iron and in which only approximately one-half is converted into steel and rolled into commercial shapes and in which considerable effort has been made to bring about the conversion of this waste energy into electrical power for distribution through the Public Utility serving the territory. However, the price which the Utility can afford to pay for this by-product power has not yet proved sufficiently attractive to invite the capital necessary to carry out the development. There are also certain handicaps which affect the situation which are not always appreciated by those not familiar with the problem. The flow of gas for small installations varies over wide limits and condenser water in sufficient quantity is frequently not available in the immediate vicinity of the furnaces.

There has been much controversy regarding the best methods of utilizing the potential energy available from blast furnace gases and the engineers are still divided in their opinions as to whether the gas engine or the steam turbine is the proper type of prime mover. It is beyond the scope of this paper to discuss this question but the following quotation from Mr. Shover's paper "Power in the Iron and Steel Industry in the United States," read before the recent World Power Conference in London, may be of interest:

"While reciprocating engines still comprise the larger proportion of power units, the turbine is coming more and more into use. In 1909 the turbine was not considered of enough importance to be listed separately in the Census Report, but the 1919 report gives 955 units aggregating 893,884 h. p. or 21 per cent of the total steam power listed. Two manufacturers of turbo-generators report records of 334 units of their make ranging in size from 300 kw. to 17,000 kw. and totaling 908,425 kw. as being in use in the iron and steel industry at the end of 1923. Of these units 66, totaling 357,375 kw. or 39 per cent have been installed since 1918.

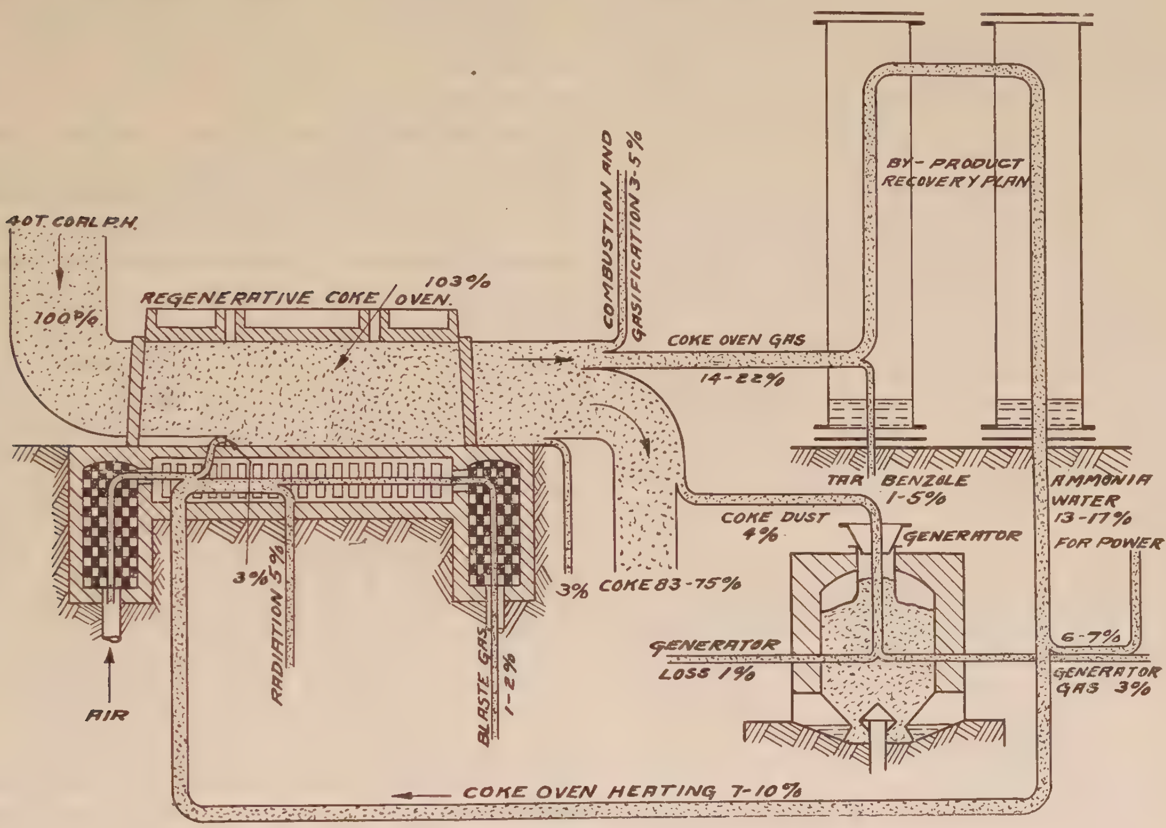

Fig. 4

The 160 per cent increase in the capacity of internal combustion engines shown in Table IX[1] would alone indicate a very radical tendency in that direction, but conditions have changed. The years 1905 to 1914 might be termed the "Gas Engine Era" in the development of steel works power, since the major portion of the total capacity was installed during that period.

1. Table IX Shover's paper gives rated horse power of internal combustion engine as follows: 1909, 208,077; 1919, 542,550, per cent change 161.

In 1919, there were 287 gas engines totaling 542,462 h. p. or 61 per cent of the capacity of the turbines and only 11 per cent of the total plant power.

Increase in speed, capacity and efficiency of the turbine, together with its lessening cost per h. p. have swung the tendency towards it, and close inquiry shows the installation of only five gas engine generating units aggregating 21,140 kw. capacity with no blowing units since 1918. This capacity compared with the 357,375 kw. turbo-generators, previously mentioned as having been installed during the same period, clearly shows which method of power generation is at present preferred. The advantages which the internal combustion engine has in regard to heat efficiency will probably bring it into favor again when fuel has advanced a certain amount in cost, (apparently to about $10.00 per ton) particularly if the installation cost can be reduced and reliability increased, but until they occur the gas engine is not likely to be restored to favor in America."

The curves in Fig. 2 show the electrical energy available from the gas from blast furnaces after deducting the amounts needed for blowing and heating the blast. One curve shows the kw-hr. available at generating station bus bars per ton (2240 lb.) of pig iron; the other, the kw. output possible in electrical power per 1000 tons of pig iron produced per day. These curves are based on 45 per cent of the gas being available for power purposes which is slightly higher than given by Hermanns. It is further assumed that one kw-hr. is produced with 25,000 B. t. u. in blast furnace gas.

The tremendous importance of utilizing the blast furnace waste gases, both from the standpoint of conservation of our coal supplies and of the monetary equivalent is clearly indicated by the following:

The Fourteenth U. S. Census gives 30,443,167 tons (2240 lb.) as the pig iron produced in 1919. Referring to the curves and assuming that 2000 lb. of coke are consumed per ton of pig iron produced, we find that there are sufficient waste blast furnace gases available for the production of power to generate 245 kw-hr. per ton of pig, or 7,480,000,000 kw-hr. for the total production of pig iron for that year. Assuming 2 lb. of coal per kw-hr. which is probably considerably less than the coal consumption in the average industrial plant, this gas is equivalent to 7½ million tons of coal.

It is interesting to note, in this connection, that John A. Hunter, in a paper presented before the American Society of Mechanical Engineers in May of this year, gives as his estimate of the coal equivalent of the waste gases 7,259,878 gross tons, which checks very closely with my estimate which was made entirely independent of his.

While there are still many of the old-fashioned beehive coke ovens in existence, they are rapidly being replaced by modern by-product ovens located at the steel plants, which makes available as a by-product large quantities of very rich gas containing approximately 550 B. t. u. per cu. ft. This gas, however, is very rich in hydrogen, which makes it unsuited for utilization in gas engines unless diluted with blastfurnace gas and is considered by most steel plant operattors more valuable for use in furnaces than for producing steam, so that very little of this energy is converted to electric power.

The flue gases of the open hearth furnaces is another source of by-product power in the steel plant. Here, too, the estimates of various authorities differ and conditions obtaining at various plants are, no doubt, sufficient to account for these discrepancies. A conservative estimate would seem to indicate that a 100-ton (charge) furnace will maintain on the average 350 boiler h. p. throughout the 24 hours, which, on the basis of two charges per day, gives 42 boiler h. p. hours per ton of steel produced.

The Fourteenth Census gives the open hearth production of steel as 26,726,036 tons, which, (assuming 9 lb. of steam, "from and at 212 deg. fahr." per pound of coal) is equivalent to 2,125,000 tons of coal which might be conserved if all the open hearth furnaces were equipped with waste heat boilers.

The Illinois Steel Company was the first to install waste heat boilers. Their installation, which was made in 1910, consisted of a second-hand Heine water tube boiler installed in the flue of a 65-ton furnace. This was followed the next year by two additional boilers at the South Works. A full description of this installation can be found in a paper, "Waste Heat Boilers for Open Hearth Furnaces," read before the American Iron & Steel Institute in 1915 by C. J. Bacon, at that time Steam Engineer of the Illinois Steel Company.

The early success of these installations has resulted in the very general application of waste heat boilers to open hearth furnaces. Referring to this subject, John A. Hunter states that there are at present 140 furnaces equipped with waste heat boilers through which approximately 500,000 tons (2240 lb.) of coal are saved annually. Comparing this with the total estimated possible saving, 2,125,000 tons, it is evident that very substantial progress has been made in this field.

In conclusion, I wish to refer very briefly to the steel mill generating plant which does not differ essentially from other large industrial power plants, except insofar as it is affected by the substitution of waste gas or waste heat for coal or oil as fuel. Like every other element in the operation of a steel plant, continuity of service under rapidly changing load which fluctuates between wide limits must be given first consideration.

Although the fuel is a by-product and is often looked upon as free, the question of plant efficiency should be given just as careful consideration in the design of a steel mill power plant as of any other industrial station and each factor affecting it carefully weighed before

making a decision. However, I believe that I am safe in making the following very general recommendations:

If more waste gas and waste heat is available than is required to meet the immediate and future demands for power, economy may be more or less ignored and the station cost kept as low as is consistent with thorough reliability of service. If, on the other hand, it is necessary to burn coal to supplement the by-product fuel, the question of efficiency at once becomes important. The cost of this supplementary fuel, however, should be taken into consideration in determining to what extent the capital investment in the station can be increased to improve the plant efficiency. Similarly, if there is an external market for surplus power, the value of this should be considered.

Technical Committee Annual Reports 1923-1924

Continued

POWER STATIONS COMMITTEE

To the Board of Directors:

Scope of the Committee

The Committee has not departed in the year past from the four main activities outlined in last year's report as:

First. Routine analysis and recommendation of papers submitted by the Meetings and Papers Committee.

Second. Securing of papers on subjects related to the Committee's jurisdiction for publication in the A. I. E. E. Journal.

Third. Special research investigation with reports and papers resulting therefrom.

Fourth. Resumé of the year's progress on power station work.

In connection with the foregoing and the subject matter, as well as the treatment of the report, which follows your attention is directed to the extract from the "Tentative Report (touching this committee) of the Committee to Review Technical Activities of the Institute" as follows:

COMMITTEE OF POWER GENERATION

Field: Cognizance of all matters in which the dominant factors are the requirements, selection, relation, installation and operation of machinery and devices necessary to the generation and supply of electrical energy, including the economic questions thereto.

Note: The expectable functioning of this committee should initiatory and determinative in the matters within its province. Subject to the approval of the Board it would have power in all matters arising therein, except such formulation of standards as is the function of the Standards Committee, including those of contact with other bodies and of arrangement for joint action where such is indicated.

Mention is made of this point because of certain criticism of two sorts which has come to the attention of the committee:

1st. That in previous years it has rather perfunctorily duplicated some of the reports of the organizations avowedly chiefly interested in operation, and

2nd. That the character of the reports has not been consistent with the dignity of the Institute primarily as a scientific body.

It is difficult to see how compliance with the procedure applied by the latter criticism can be made consistent with the field proposed for the realignment of the committee activity, if indeed there are sufficient matters of purely technical and scientific interest arising yearly within the scope of this committee to justify its continued existence without in any way treating of practical operating conditions.

As to the first criticism it may be sufficient to say that there is a feeling among several members, at least, of the committee that such practical operating reference as have heretofore appeared would be of value to a certain portion of the Institute not connected with associations of operating companies in various kinds of power station activity.

It would seem desirable that your body take under advisement from year to year the questions whether the active functioning of a committee like this could to advantage be, at least temporarily, discontinued; whether the committee is functioning along the most desirable lines; whether the committee is functioning in these lines to best advantage both intensively and extensively?

Accomplishment

During the year again there has been routine consideration of papers submitted by the Meeting and Papers Committee.

As to the initiating the publication of papers some progress has been made and is still in the making.

The idea of interesting manufacturers and colleges equipped with suitable laboratories in special research investigation along lines kindred to the activity of this committee has been considerably advanced. Several such laboratories are in a position to make at least initial analysis of the requisites of the problem as soon as specific cases can be laid before them. This calls for initial action from the members of the Institute through this committee. It must not, however, be expected that such research, except in special cases, can be carried on without providing the necessary funds for it. But it is much to know that facilities in both equipment and personnel actually exist for carrying on many problems, for which many might suppose a

considerable period of preparation and large expense would be necessary.

Résumé of the Year's Progess in Power Station Work

It is scarcely possible to attempt to review power station progress without trenching upon ground covered by the 1923 reports of the Electric Apparatus and Prime Movers Committee of the N. E. L. A. and the Power Generation Committee of the A. E. R. A. to which particular reference is made for a wealth of information and detail. Certain points, however, deserve special mention and are given with somewhat definite treatment.

In the preparation of this portion of the report each member of the committee was made responsible for certain topics; failure of presentation of any subject that might appear important in a report of this character is to be attributed to the inability of the individual to furnish the appropriate data. Several members of the committee have expended no little time and energy in the preparation of their contributions.

General

The most impressive feature of the year's power station work was the unusually large building activity of both steam and hydraulic plants, amouting to approximately 5,000,000 kv-a. of generating capacity and the continued tendency toward larger stations and larger units.

Hardly in any other year than during 1923 have so many schemes been introduced to increase the steam power plant efficiencies. The insecure and the varying grades and qualities of coal have given fuel oil and pulverized coal a very strong impetus. With fuel oil there happened to be a heavy over supply, therefore bringing a low price, and with pulverized coal the recognized advantage of being able to use various grades of coal within the same furnace without great trouble, its flexibility and ability to maintain high efficiencies were the major inducements for so many changes and new installations. It appears that although for some time pulverized coal had been used, no uniform practise has developed. The mode of firing, especially, appears to lack satisfactory solution. On the other hand a considerable number of improved stokers has been installed, and they may be still further developed in the future under the pressure of the competition of pulverized coal. The sizes of boilers and furnaces have rapidly increased to considerable dimensions and it has been proposed to build a single boiler to supply a 30,000 kw. turbine-generator unit. Such a boiler would have a heating surface larger than the biggest boiler now used, by about one third. Recent boiler designs show a tendency to increase the heating surface exposed to radiant heat and some contemplate lining the entire furnace with heating surfaces. Should this be successful, the difficulties with refractories would be overcome, and the operation of boilers at high rating with preheated air would gain increased impetus. Investigations of superheated steam temperatures in connection with varying boiler loads have led to various superheater developments. Hand in hand with high ratings the furnace volumes have so rapidly increased in size and cost that future growth may be limited by economical considerations. High ratings brought higher flue gas temperatures and therefore the economizer was brought to the front again. For the same reason the demand for better feed water developed more efficient water treatment plants, evaporators and deaerators.

The striving for high efficiencies has brought higher steam pressures and with it various new cycles and larger capacities of generator units which have increased to 62,500 kv-a. These larger units are mostly of cross or tandem compound arrangement, especially where higher steam pressures are contemplated in connection with a reheating cycle.

With the innovation of bleeding main turbines for feed water heating, the house turbine direct connected to main unit has been developed. As for steam pressures, installations are being made for 400 and 500, 1200 and 3200 pounds, the last one by the English Electric Company, at Rugby, England. The maximum temperatures considered for the above pressures are between 700 and 800 deg. fahr. With these high steam pressures and temperatures the reheating or Ferranti cycle, the regenerative cycle and the combined reheating and regenerative cycle are given most attention.

Toward the end of the year much was heard of the mercury turbine which has been under development by the General Electric Company since 1914.

As far as valves and fittings are concerned it has been reported that tentative standards for pressures up to 900 lb. per sq. in. and at a temperature of 750 deg. fahr. have been agreed upon. Besides this rapid departure from established steam practise, the economic success of which only time can prove, the leading manufacturers have carried on research and improvements on established equipment. Two out of the three largest builders of equipment are giving turbines resonance tests before leaving the shops, and much thought is given to generator cooling, of which the closed system of ventilation appears to be gaining in favor. The operating results of modern steam turbines have improvedly markedly.

The development in hydraulic plant equipment has followed the general trend of steam plants, both in improvement of design and construction, and in size of units. The tendency toward large sized vertical units continued, and more attention was given to the question of suitability of design for the hydraulic conditions and load requirements, and careful working out of the details of design of auxiliary equipment required for the proper control and protection of the main units. The operation of the various control mechanisms electrically from the switchboard has come into more general use, and the details of switchboard control mech-

anisms as well as refinements in the setting, and the adjustments of such mechanisms have been worked out successfully.

The tendency in large hydroelectric stations, consisting of two or more vertical units seems to be in favor of a single floor station, with the main floor at approximately the elevation of the top side of the turbine casing, or about the center line of the main turbine steady bearing. With this type of station layout the generator is generally supported on reinforced concrete piers and the switchboard and remote control mechanism are located in a gallery off the main generator room, at about the elevation of the generators. This arrangement gives the operator vision of the generators, turbine equipment, governors, and all auxiliary apparatus.

Outstanding, as to size, are the 70,000 h.p. hydraulic turbines for the Niagara Falls Power Company, operating under a head of 213½ feet, at a speed of 107 rev. per min., and connected to a 65,000-kv-a., three-phase, 25-cycle, 12,000-volt generator. These units are also equipped with air brakes for bringing them to a stop quickly when shutting down.

The hydraulic turbine of the Oak Grove plant, of the Portland Railway Light & Power Company, at Portland, Oregon, has the highest head reaction wheel built to date. This is a 35,000 h.p. vertical turbine designed for operation under an average net effective head of 875 feet, the static head being 960 feet. The unit will operate at a speed of 514 rev. per min. and is complete with governor operated, automatic water economizing pressure relief valve; 72-in. water and electric motor-operated remote control butterfly valve; Moody type spreading draft tube and special oil pressure governor. The penstock providing power water for this unit is comparatively short but on account of its combination with a flow line several miles in length, the regulation problem involved has been solved by the installation of a Johnson differential surge tank hewn from the solid rock. A Johnson plunger type valve is provided at the upper end of the pipeline just below the surge tank, equipped with remote control and with emergency control features to provide for its mechanically closing down in the event of rupture to the pipeline or for any other reasons which would increase the velocity of the flow within the line above normal.

A notable improvement in hydraulic turbine design during the year, has been the use of the rubber seal rings or clearance rings in a number of large turbine installations. Former constructions have required metal rings at the clearance spaces between the rotating runners and the stationary portions of the casing. Usually these rings have been made in pairs, of which the rotating part is steel and the stationary, bronze.

The governor problem has been given special attention, and much improvement in speed control and regulations has resulted. Present-day governors are made with various accessories and auxiliaries, the use of which affords practically absolute safety and protection to the generating equipment under all phases and conditions of operation. Owing to the large size of the present-day electrical systems and extremely large inherent flywheel effect available for speed regulation, it is now very seldom that it becomes necessary to require that any additional flywheel effect be provided in the generator, or the hydraulic prime mover, to satisfy speed regulation requirements, as the inherent flywheel effect of the machines added to that of the system into which they will be connected is generally more than ample. With this condition there is also a strong and proper tendency on the part of the operators to simplify their pipeline and surge problems by increasing the length of time required for the governor stroke. With modern governors the stroke time may be regulated to meet conditions exactly, and the time for the opening stroke may be made different from that of the closing stroke.

Considerable progress was made during 1923 in various design features and in the control mechanism of butterfly valves. The remote electrical control of such valves when placed at the upper end of a pipeline or at the outlet of a surge tank has been quite generally adopted. A system of distant control has been developed which insures the correct operation of the valve at times of emergency without danger of the valve being operated inadvertently by accident to the control circuit through lightning or mechanical injury from falling trees, etc. Such valves can, of course, be readily operated by means of the controller at the valve and by means of suitable relay mechanism can also be operated from the powerhouse. Most installations are arranged to allow closing of the valve from the powerhouse but not opening it from that point, thus providing for the necessity of closing the valve in case of a serious accident at the power house, or to the pipe line, but not allowing the automatic opening of the valve from the power house with the pipe line empty, as this might cause serious damage or even loss of life. Indicating lamps are provided to show at the power house switchboard the open or closed position of the butterfly valve, and the operating motor of the valve is equipped with limit switches to prevent overtravel of the valve at either end of the stroke.

Attention has been given to increasing the life of generators as well as improving their stability. Use of relays for protection, particularly of the thermal type, has been quite a factor.

More confidence in extremely high-voltage transmission has developed from the results of the 220,000-volt systems put in operation during the year by the Southern California Edison and the Pacific Gas & Electric Companies. Transformers and switching gear for such service contributed much to the success and indicate that distinct progress has been made in the design and construction of such equipment.

For the higher voltages, switching apparatus and transformers are generally installed outdoors on ac-

count of excessive housing costs, and there is a tendency for the lower voltages to isolate the phases and isolate the entire switch house from the main power station building.

Mention should be made of supervisory control of generating stations from a central point which is generally in the load dispatcher's office, where is located the system diagram board on which switches are indicated by small colored lamps which at all times give complete information concerning operating status of the entire system. The development of the carrier-current system of telephony, which effects communication by means of high-frequency currents superimposed on the power conductors of the transmission lines, has increased the scope of usefulness of supervising control, particularly of hydroelectric stations located in remote districts.

Switches and Circuit Breakers

During the last few years the rapid increase in capacity of a number of large systems has reached the point where it has become a difficult matter to secure satisfactory oil circuit breakers of sufficient interrupting capacity to protect the system even when current-limiting reactors, to limit the short-circuit current, are used in every way practicable. The manufacturers of oil circuit breakers are making herculean efforts to keep pace with the requirements of the industry but to date no breaker with an interrupting capacity greater than 1,500,000 kv-a. has been installed.

The manufacturers have been handicapped in their design on account of their inability to test their breakers to destruction due to lack of generator capacity. To date very few large central stations have been willing to allow high capacity tests to be made on their system. It is believed that oil circuit breakers of very much greater interrupting capacity than have been manufactured, can be successfully made providing the need is great enough to justify the cost.

In order to limit the number of short circuits in power stations and minimize the damage done in case trouble occurs on the bus or switching equipment, a segregated phase scheme, either horizontal or vertical, is used in a number of the latest and largest stations built during the last two years.

Gang-operated disconnecting switches interlocked with the oil circuit breakers are to a great extent replacing single pole switches operated by a switch hook. In one of the newest large central stations practically no disconnecting switches are used for disconnecting the oil circuit breakers from the bus or line. The disconnection of the breakers is accomplished by lowering them below their normal position, thus breaking the connections and isolating the breakers.

The use of truck type panels for controlling station auxiliaries is increasing. A number of the latest large stations have installed or are contemplating the installation of equipment of this type.

Water Wheel Type Generators 1923 Devleopment

The outstanding developments in regards capacity of units are:

a. 65,000-kv-a., 107-rev. per min., 25-cycle, 12,000-volt generators for the Niagara Falls Power Company.

b. 55,000-kv-a., 187½-rev. per min., 25-cycle, 12,-000-volt generators for the Queenston Development of the Hydro Electric Power Commission of Ontario.

c. 28,000-kv-a., 428-rev. per min., 50-cycle generators, suitable also for 60 cycle operation at 514 rev. per min. with a guaranteed overspeed of 85 per cent for the Southern California Edison Company.

Some features worthy of mention in the case of one design for the 65,000-kv-a. units, are the elimination of the lower guide bearing on the generator, and the incorporation of a 650-kv-a. 2200-volt service generator within the main unit, the rotor of which is immediately above the main rotor and the stator suspended from the main upper bracket. The main rotor spider is made up of two wheels each consisting of seven cast steel sectors bolted to cast steel hubs. The main upper bridge is also of cast steel with ten radial arms bolted to a central hub.

The 55,000-kv-a. generators are very similar to the 45,000-kv-a. units built a year or two ago. In the design of one of the manufacturers an extra wide space is provided in the stator iron to facilitate removal of the armature coils. The first of these units went into operation in slightly less than one year from date of placing the contract.

There has been considerable change in the general design of smaller units; generators have been developed with the thrust bearing located immediately below the rotor spider with the top bracket eliminated entirely. With this type of construction reducing the turbine pit diameter to an absolute minimum there should be a considerable reduction in the cost of the unit. This type of design should also require considerably less head-room for erection, with a consequent saving in power house superstructure cost. In fact it might be possible to dispose of the power house superstructure entirely by providing a weather proof housing over each unit, which could be readily removed if necessary, and all operations carried on by chambers provided in the sub-structure.

Automatic generating stations are receiving more attention, as evidenced in the increasing number of installations such as some developments of the Hydro Electric Power Commission of Ontario, where in each case two generating stations each containing three 2000 kv-a. generators will be operated from a third station located four and six miles from the automatic station.

A contract for generators placed during the year and worthy of mention is that placed by the Quebec Development Company for eight 30,000 kv-a., 13,000-volt, 112-rev. per min. units. This is notable not alone on

account of the size of the units but on account of the large number included in the contract.

Fly-Wheel Effect of A. C. Waterwheel Generators

In connection with the design of water wheel generators the question as to the most suitable flywheel effect of generator usually comes up for discussion, as very frequently the flywheel effect which is inherent in a normal design of generator is not considered sufficient from the point of view of waterwheel speed regulation and the advisability of adding extra weight to the generator rotor must be taken into consideration. It was thought therefore, that a brief study of this feature might well be considered in the present report of your Power Stations Committee.

The basic formula generally used for computations of speed regulation of water wheels is as follows:

$$d = \frac{800{,}000 \times H.\,P. \times T}{W\,R^2 \times (R.\,P.\,M.)^2} \qquad (1)$$

Where T is the governor time in seconds, *i. e.* the time taken to operate the gates, h.p. is the change in horse power load which causes the governor to act; $W\,R^2 =$ flywheel effect of the rotating elements including the water wheel runner and shaft (expressed in lb. — feet^2); rev. per min. the initial speed expressed in revolutions per minute. The resulting speed regulation d as given by this formula is expressed as a decimal; ($100 \times d =$ per cent speed change). This formula is approximate but sufficiently accurate for average conditions.

Formula (1) is more frequently used in another form as follows:

$$d = \frac{800{,}000 \times T}{K} \qquad (2)$$

$$\text{Where } K = \frac{W\,R^2 \times (R.\,P.\,M.)^2}{H.\,P.} \qquad (3)$$

K is known as the regulating constant and h. p. is the full load rating of the water wheel.

The constant K may range from 2,000,000 with small machines, particularly direct current generators, to 10,000,000 or more with large capacity, medium, or high-speed units. Flywheels or extra weight in the rotor are sometimes added, but K in commercial plants rarely, if ever, exceeds 12,000,000. There is some difference of opinion as to the desirable minimum value of K for governor operation; some makers have gone as low as 3,000,000, but in general 4,000,000 may be taken as a reasonable lower limit. A value of 3,000,000 is suitable only for open flume conditions where there is no large moving column of water to handle as in a closed penstock.

If the governor time on the average is taken as 2 seconds and $K = 4{,}000{,}000$, Formula (2) gives d a value of 0.4 or 40 per cent for a full horse power load change. This figure is of course, rarely reached in practice while the unit is operating on load, but serves as an indication of the extreme that might be reached if the unit were suddenly disconnected from the line. It is also a rough indication of the regulating characteristics of the unit. It should be remembered that the majority of waterwheel units are not isolated, but are tied in on a system with a number of other generators. The system is, therefore, usually sufficient to make the load changes on any one unit small in comparison to its rating, and the total connected flywheel effect of the system is such that the load changes have relatively little effect from the standpoint of speed change. Modern systems are becoming so large that the governor as such is practically inoperative under usual conditions and serves mainly for convenience in starting and stopping the unit, for adjusting the load from the switchboard, or as an emergency shut-down device in case of emergency. With isolated units the governor is, of course, necessary for regulation in most cases.

Plant operators and operating departments have, however, handled units to such a great extent with governors, that as a rule they are of the opinion that governors are inherently required for the control of hydroelectric units. This general attitude has resulted in the requirement of a regulating constant of 4,000,000 or more in most modern plants, in spite of the fact that the generator frequently works out with such flywheel effect as to give normally a smaller regulating constant. Naturally weight added to the generator rotor increases the cost and with vertical machines increases the weight on the thrust bearing, thus in many cases increasing the size and cost of the latter. Increased $W\,R^2$ over and above that inherent in the normal design will also result in most cases in a slight reduction in generator efficiency owing to the increased windage and friction loss.

Some hydraulic engineers as well as those engaged in the operation of hydroelectric plants are of the opinion that the usual hydroelectric unit arranged for an extended interconnected power system of considerable magnitude, particularly such systems as have a portion of their generating capacity in steam, do not require a governor, at least not one as usually built, and that it is not necessary to load the generator with extra weight for purposes of regulation. The reason for this viewpoint is found in the fact that a hydroelectric unit is intended primarily for the purpose of delivering the maximum possible number of kilowatt-hours per year to the system from the flow in the river and at the available head. A governor, as such, defeats this purpose to a greater or less extent, as any movement of the gates away from the point of best efficiency, decreases the net kilowatt-hour output; and a governor can regulate only by moving the gates. This loss of output is overcome in plants where the operation is most closely watched by running the governor on what is known as the load limit device. When the governor is so operated, it is ineffective from a speed regulation standpoint

unless the load is reduced so as to cause the governor to close the gates either partially or wholly. In large systems, such as are becoming prevalent, the regulation of an individual unit is of little consequence and, on this account, excess $W R^2$ in generator is becoming of less and less value. This factor together with the feature of maximum kilowatt-hour production will doubtless influence the design of units for operation on extended networks, in the direction of a gate opening device rather than a governor of usual type, this device being combined with an emergency shut down mechanism which would become operative in case the unit should lose its load or the speed tend to increase unduly. Such an arrangement would be much simpler than the regular type of governor. With control of this kind the gate mechanism would be controlled by hand from the switchboard and by float from the head water level. A number of units are at present operated successfully in this way.

Assuming that no extra weight is added to the generator rotor to increase the flywheel effect, the question arises as to what $W R^2$ may be reasonably expected in a generator of normal design and of given kilovolt-ampere output at given speed. Can a formula be developed from which the $W R^2$ can be determined? From the nature of the problem it is plain that no general formula can be developed that will give the WR^2 because a machine of given kilovolt-ampere output at given speed may be designed with different diameters of rotor. One design may use a rotor of relatively large diameter, high peripheral speed, and short axial pole length. The same kilovolt-ampere rating might on the other hand be made with a rotor of relatively small diameter, lower peripheral speed and longer axial length of pole. Both machines might be entirely satisfactory as generators, but their flywheel effects would be quite different. Again, the mechanical design of the rotor may have a decided influence on the $W R^2$, so that on the whole there can be a wide variation for machines of the same rating, even if the generators are equally good in other respects.

It has been felt by the Committee that some information as to the normal $W R^2$ of waterwheel generators as actually built would be of value as it would at least give an approximate idea as to what might be expected in machines of various ratings. With this in view, information was collected on quite a large number of units covering a wide range in speed and output and designed by three leading manufacturers. These flywheel effects have been plotted, using the ratio $\frac{\text{kv-a.}}{\text{R.P.M.}}$ as abscissas, and $W R^2$ expressed in lb.-ft.^{2} as ordinates. The kilovolt-ampere rating in each case was taken as the maximum rating of the generator and the $W R^2$ is that inherent in the design of the machine; *i. e.* it includes no extra added weight in the rotor. The curve shows an approximate average but this is added as a matter of interest only, and Fig. 1 is chiefly of value as indicating values of flywheel effect as they worked out in waterwheel machines as built and in operation. The general tendency seems to be to eliminate added $W R^2$ especially for machines used on large systems so that generators built in the future will doubtless correspond more nearly with those indicated in Fig. 1, as having the lower values of flywheel effect rather than the higher except in cases where a high $W R^2$ may be the result of mechanical features necessary to take care of overspeed, etc.

Temperature Standards

The question of temperature standards has been for some time in the hands of a subcommittee of the Institure Committee on Standards and the American Engineering Standards Committee for official action, to the progress reports of which as well as to the Committee on Electrical Machinery reference should be made for details of the present status of the recommendations.

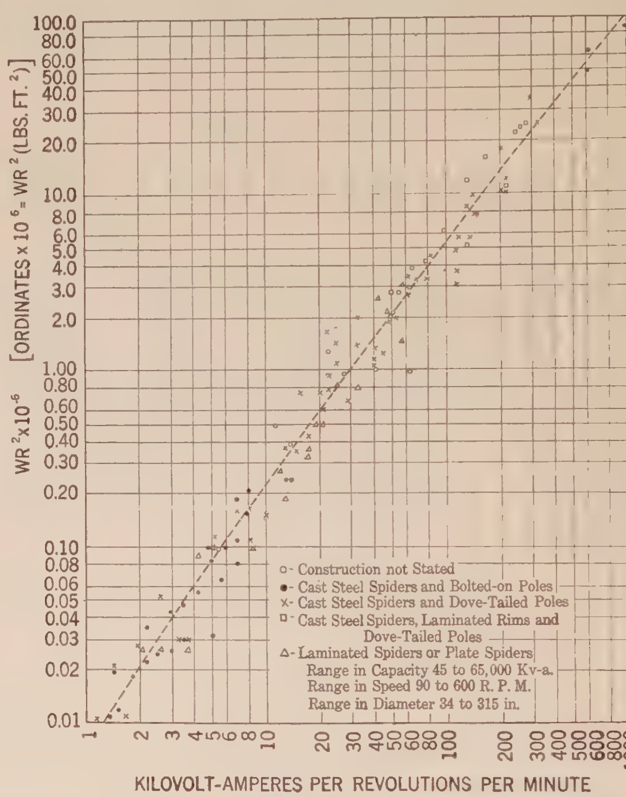

Fig. 1

Electric Drive and Control of Auxiliaries

Practically all the auxiliaries at the new station of the Edison Electric Illuminating Co. of Boston now under construction on the Weymouth Fore River will be driven by a-c., 60-cycle motors. The use of alternating current for this service, was decided upon after a careful comparison with direct current.

Motors and control that are essential to continuous plant operation are designed to be automatically started, upon restoration of power, after an interruption.

On the larger constant-speed motors, a double squir-

rel-cage winding is used which reduces the starting current to approximately one-half that of the usual squirrel-cage design and allows the motor to be thrown directly across the line.

Maximum reliability and efficiency of the station service energy supply are obtained by the use of a 2500-kv-a., 2300-volt auxiliary generator direct connected to the main generator shaft and supplying power to a definite group of auxiliaries. Relay service is provided from buses which connect through transformers to the main 14,000-volt buses. An automatic face plate voltage regulator is used with each auxiliary generator.

It is intention of this report to describe the motor and control equipment of the station auxiliaries giving the reasons which led to its selection. No attempt will be made to compare electric with steam, or steam electric drives, as it seems to be generally recognized that station auxiliaries should be as completely motorized as possible.

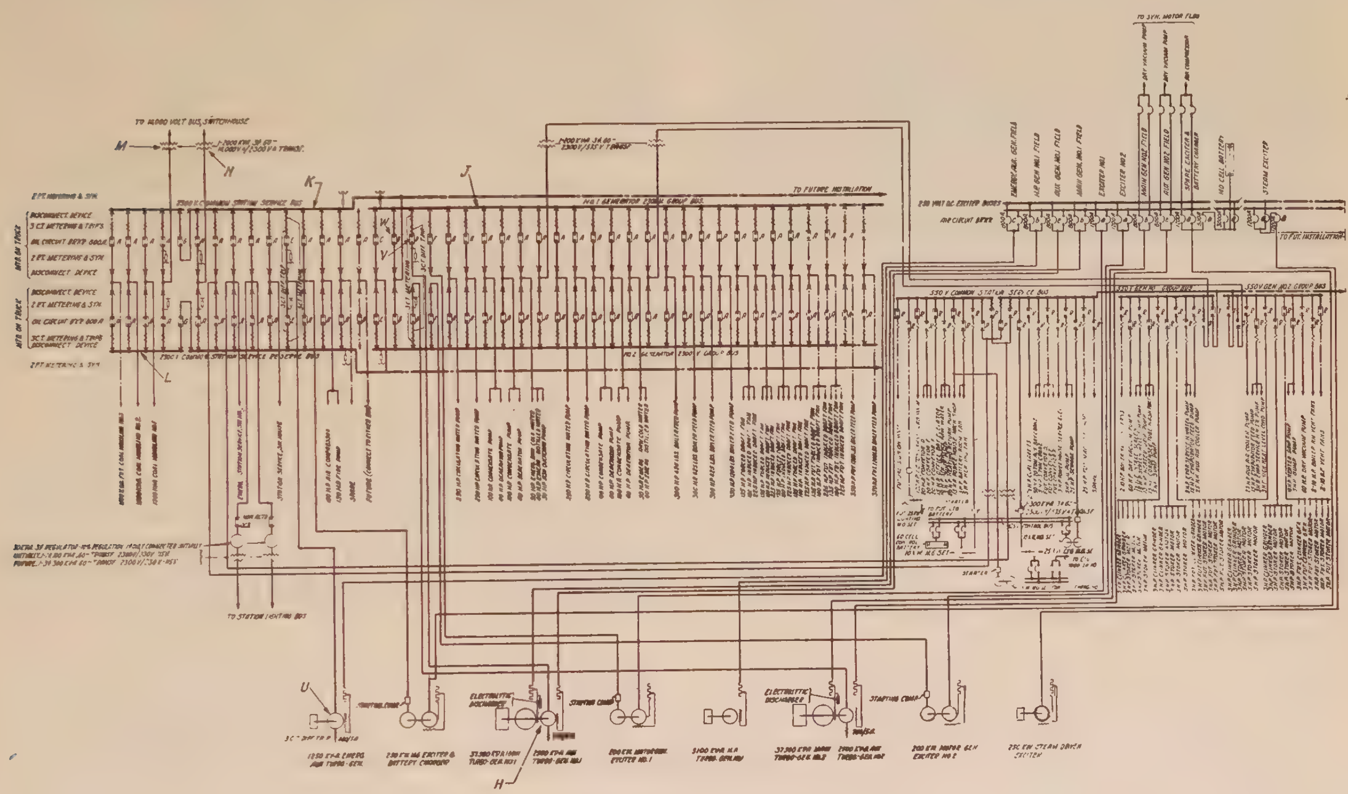

Fig. 2—One Line Diagram—Electrical Equipment Weymouth Power Station

H 2300-Volt Auxiliary Generator 2500 Kv-a.
J 2300-Volt Group Bus
K 2300-Volt Station Service Bus
L 2300-Volt " " "
M 2000-Kv-a. Transformer
N 2000-Kv-a. Transformer
U 1250-Kv-a. Emergency Generator
V Oil Circuit Breaker for Auxiliary Generator No. 1
W Oil Circuit Breaker for Group Bus No. 1 to Station Service Bus

Description of System

Fig. 2 shows a one-line wiring diagram of the auxiliary power system. There is a 2500-kv-a., 2300-volt auxiliary generator *H* on the same shaft as the main generator. This auxiliary generator is connected to a 2300-volt group bus *J* to which are connected all the auxiliaries required for the main unit, and in addition, a portion of the auxiliaries in the boiler house. This group bus is relayed from two 2500-volt buses *K* and *L* which are supplied with power from two 2000-kv-a. transformers *M* and *N* connected to the main 14,000-volt buses and also from a spare 1250-kv-a., 2300-volt turbo-generator *U*. These 2300-volt buses are designated "Common Station Service Buses" and supply power normally to all auxiliaries, such as cranes, elevators, and coal handling equipment, the operation of which may be temporarily interrupted without affecting power production. The boiler house auxiliaries and also the important auxiliaries for the main units, have selector breakers which allow them to be supplied with power from either their own generator group bus or from one other generator group bus. The only auxiliaries in this station that are steam driven are a high-pressure-boiler feed pump, a low-pressure-boiler feed pump and a steam-driven exciter. Normally, the steam-driven units will not be running. All other auxiliaries are driven by alternating current motors. The valves, however, are operated by 220-volt, direct-current motors.

The design is laid out to afford an independent system of two common station service and four generator group buses for every four main turbo-generators.

Alternating vs. Direct Current

One of the first considerations in determining the type of electric drive, was the choice between alternating-current and direct-current motors. Determination of the relative economy of the two types of equipment depended largely upon the duty cycle assumed for the

various auxiliaries and also upon the load factor of the plant. Comparative figures were made for both, using various schemes for obtaining the power supply.

The most economical direct-current scheme seemed to be one having an auxiliary alternator on the main generator shaft feeding direct to a 550-volt direct-current synchronous converter. The most economical alternating current scheme appeared to be the one adopted. A comparison of these schemes is shown in Table I.

This analysis indicated that for this station, alternating current was at least as economical as direct current and the layout was simpler. Smaller cables and conduits could be used and thus possibly wall and floor thicknesses could be reduced. Alternating current motors were, therefore, adopted.

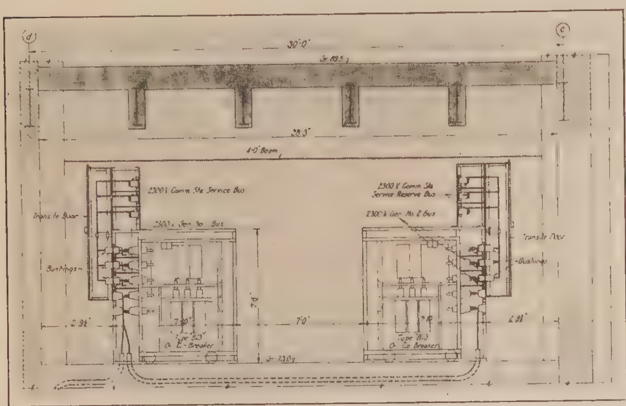

Fig. 3—Cross Section-Station Service Room Weymouth Power Station

Power Supply

The auxiliary generator on the main generator shaft not only offers a power source of maximum efficiency but also allows unit operation through the group bus, thus securing a very high degree of reliability. It is estimated that the normal auxiliary power required by each 30,000-kw. unit will be about 800 kw., with about 450 kw. additional for the boiler house auxiliaries necessary to operate one turbine generator, making a total of approximately 1250 kw. for one main unit. One-half of the boiler room auxiliaries for three high-pressure generators add 300 kw., making a total of about 1550 kw. under normal conditions. Under emergency conditions, when it may be necessary to force some boilers up to their maximum rating, it is estimated that the load on one auxiliary generator will be approximately 2100 kw., which it will carry for a period sufficiently long to start other boilers.

The auxiliary generator is capable, not only of supplying power for its own auxiliaries and its portion of the boiler house load, but also under normal conditions of carrying the auxiliaries required to start another unit. Such operation is provided for through selector oil circuit breakers as previously described. The transformer capacity between the 14,000-volt bus and 2300-volt bus has been made sufficiently large to supply the common station service load and in addition, to relay one of the 2500-kv-a. auxiliary generators. In case, however, of a complete power station shutdown it would be possible to start the plant by means of the steam-driven exciter, the spare 1000-kw. steam-driven generator and the steam-driven boiler feed pump.

TABLE I

COMPARISON OF AUXILIARY DRIVE FOR THE WEYMOUTH POWER STATION OF THE EDISON ELECTRIC ILLUMINATING CO. OF BOSTON, WEYMOUTH, MASS.

Assumes 6—30,000 Kw. Units, Maximum Load 150,000 Kw. Does not Include Common Station Service

						Scheme 1—D-c. Motors except Common Station Service. Auxiliary Generators. Rotary Converters. House Turbine.				Scheme 2—All A-c. Motors. Auxiliary Generators. Transformers House Turbine.			
						Annual Costs				Annual Costs			
Equipment	Rated kw. or kv-a.	No.	Hours per Year in Service	Eff. % D. C.	Eff. % A. C.	First Cost	Fixed Charges & Maintenance	Power @ ½c.	Total	First Cost	Fixed Charges & Maintenance	Power @ ½c.	Total
Auxiliary Generators	2000	6	5000	97	97	$90,000	11,600	6,960	$18,560	$90,000	11,600	6,600	$18,200
House Turbo-Generator	2000	1	7000			41,500	6,250	3,900	10,150	..	..	..	..
House Turbo-Generator	1000	1	..			..	..	..	..	22,000	3,300	..	3,300
Transformers, 14,000-v., 3-phase	2000	2	8700			..	..	..	..	15,000	1,500	700	2,200
Transformers, 14,00-v., 3-phase	1500	2	8700			11,000	1,100	..	1,100	..	..	..	..
Syn. Converters	2000	6	5000	98		123,000	18,500	3,480	21,980	..	..	..	..
Syn. Converters—Spare	2000	1	7000	..	..	20,500	3,100	..	3,100	..	..	..	..
Wiring				96	99.3	136,000	16,300	8,100	24,400	70,000	8,400	1,500	9,900
Switching for Units						150,000	18,000	..	18,000	250,000	30,000	..	30,000
Motors				90.0	85.4	475,800	71,340	192,210	263,550	548,000	77,770	202,870	280,640
Totals				80.8*	81.8*	$1,047,800	146,190	214,650	$360,840	$995,000	132,570	211,670	$344,240

*This figure is not the product of the efficiencies in the table on account of the common station service.

Excitation System

For each main turbo-generator there will be a 200-kw., 250-volt motor-generator set for excitation, the motor being connected to the 2300-volt generator group bus. In order to provide excitation in starting up the station independently of any source of power supply, a 250-kw. steam-driven exciter will be installed. The turbine of this exciter will supply low-pressure steam for heating. To insure a source of excitation which will be instantly available in an emergency, a 140-cell type *G*, exide storage battery and end cell switch is to be installed together with a 250-kw. motor-generator set for charging. This motor-generator set can also be used as a spare exciter. The battery has a discharge rate of 2106 amperes for thirty minutes. All exciters are connected through selector air circuit breakers to duplicate exciter buses. The fields of all synchronous generators are connected through selector breakers to these buses which are also provided with sectionalizing switches.

Power Distribution

Truck type switchboards are used to control the 2300 volt circuits. These trucks are equipped with oil circuit breakers of the *B*-13 type, redesigned, however, for finger type contacts and also for clearances of at least 5 in. between phases and 3 in. to ground. The rupturing capacity is ample to take care of the service.

Analysis indicated that the use of reactors with smaller circuit breakers in each station feeder would cost more than high capacity breakers without reactors and the latter arrangement was adopted. The reactors also have the disadvantage of introducing a very large voltage drop when motors are being started.

Operation

The switching arrangement adopted for the auxiliaries allows considerable latitude in the method of operation. At the present time, the following is contemplated:

In starting up the plant, the 2300-volt auxiliary bus will be energized either from the main 14,000-volt bus connected to the system or from the steam-driven auxiliary house turbo-generator. Assume that No. 1 main generator is to be put into service. When No. 1 main generator has been synchronized to the 14,000-volt bus, the No. 1 auxiliary generator oil circuit breaker *V* will be closed and the breaker *W* connecting the generator auxiliary group bus to the common station service bus will be open manually. In shutting down a unit, the auxiliaries that are required to remain in service can be transferred to another generator group bus. This is accomplished by means of a single control switch which automatically opens one selector breaker and closes the other after the first one has opened. If it is found undesirable, however, to interrupt power to the motors momentarily under normal operation, the generator group bus can be connected to the common station service and the circuit breaker between the auxiliary generator and its bus can then be opened. No difficulty is expected due to any phase displacement through the station transformers, as the auxiliary generator is so wound and constructed with respect to the main unit, that at no load, both generators are in synchronism. On account of the high reactance in the circuit, it is not expected that there will be any disturbance if it should become necessary to synchronize the auxiliary generator with the main generator through the transformers.

Reliability of Power Supply

Interruption of auxiliary power supply might be caused by any of the following conditions:

1. Failure of the auxiliary generator or loss of its field.
2. Failure of the main generator.
3. Overspeeding of the turbo-generator.
4. Failure of an oil circuit breaker on the auxiliary bus to function, or a short circuit on the generator group bus.

In case the auxiliary generator should fail, the differential relays would trip out the generator breaker and close a selector oil circuit breaker to the station service bus, thus keeping power supplied to the auxiliaries. In case the field of the auxiliary generator should fail a low voltage relay would trip out the oil circuit breaker of the generator and automatically close the breaker to the station service bus. Failure of the main generator would cause its differential relays to operate, which in turn would operate the differential relay of the auxiliary generator and close the selector breaker to the station service bus. In case of a severe disturbance on the system which would be sufficient to overspeed the generator and shut off the steam, it is estimated that the inertia of the rotor would be sufficiently great to keep the auxiliary generator running at sufficient frequency to supply power to the auxiliaries, while the main oil circuit breaker is tripped and the throttle again opened. It is expected, however, that the auxiliary load remaining on the unit will prevent overspeed sufficient to trip the throttle even though the main load be entirely lost. Failure of an auxiliary oil circuit breaker or a short circuit on the group bus, would affect only that particular group until such time as an operator can transfer to another bus.

Regulation

Each auxiliary generator is equipped with a face plate regulator, which automatically operates the field rheostat and maintains constant voltage. Relays are provided to ring an alarm in case of excess or low voltage due to sticking contacts.

Motors and Control

General Description. In general, all motors over 25 h. p., are rated 2300-volt, 60-cycle, 40 deg. All motors of 25 h. p. or less are rated 550 volts. Motors that are fed through trolleys are rated at 550 volts. Motors for operating valves are rated at 220 volts direct current.

The motor and control equipment of all auxiliaries upon which continuity of station output is dependent is so designed that on restoration of auxiliary power after an interruption, the auxiliaries will automatically be restored to service.

This is accomplished on squirrel-cage motors of 25 h. p. or larger by means of a double squirrel-cage winding which permits the motor to be thrown directly across the line requiring a starting current of a little over four times the rating of the motor. On slip ring motors, this is accomplished by means of an automatic contactor, the opening of which inserts a block of resistance in the rotor circuit which resistance is automatically short circuited after the current has declined to a definite value. On brush shifting motors a pilot motor restores the brushes to starting position.

Forced Draft Fan. Each forced draft fan is driven by a B. T. S. 135-h. p., 2200-volt, 1200-rev. per min. commutator type, brush shifting motor. The motor is thrown on the line by means of contactors which are controlled from a push button station mounted on a control board located in front of the boiler and from a similar station located at the motor. The brushes are shifted mechanically by the Bailey combustion control system. Variations in the steam pressure or the furnace draft, cause the Bailey mechanism to increase or decrease the speed of the motor. Upon loss of power the main line contactors open and cut the motor off of the line. When power is restored, the brushes are shifted back to the starting position by means of the Bailey mechanism; the main line contactor closes and the motor comes to the speed required by the combustion control system. In order not to reduce the volume of air while transferring the motor from one bus to another a time-delay prevents opening the main line contactors or returning the brushes to the starting position during this operation.

Induced Draft Fans. Each induced draft fan is driven by a 100-h. p., 2200-volt, 600-rev. per min. slip ring motor, and a 225-h. p., 2200-volt, 900-rev. per min. slip ring motor. Each motor is connected to the fan by means of a flexible coupling. The 100-h. p. motor is thrown on the line by means of a contactor which is controlled from a push button station mounted on the control panel located at the boiler and from a push button station located at the motor. A drum controller with the necessary resistors in the secondary circuit, provide for speed control of this motor. This drum controller is operated mechanically by the Bailey combustion control system. When the load exceeds the capacity of the 100 h. p. motor, the line contactor in the 225-h. p. motor circuit is energized through contacts on the 100-h. p. motor drum controller and the 100-h. p. motor is disconnected from the line. The 100-h. p. motor is designed to withstand speeds up to 900 rev. per min. without injury. The drum controller for the 225-h. p. motor is also operated by the Bailey mechanism. Upon loss of power, the contactors open and the motor shuts down. Upon restoration of power, the drum controller is returned to the starting position by the Bailey mechanism, the 100-h. p. motor is energized and the fan comes up to speed in the normal way. As in the forced draft control, a time delay is provided in the control to allow for transferring the motor from one bus to the other without returning the controller to the starting position.

A description of the motor and control equipment for other auxiliaries is given in Table II.

Switchboards

Benchboards for a number of large installations have been made completely of sheet steel including panels which heretofore have been of slate. A new type of switchboard lamp has been developed, arranged for mounting on the front of the board. A resistance in series with it replaces the usual small fuse. For some installations in metropolitan districts where space is at a premium, control apparatus of unusually small dimensions has been used satisfactorily. In a number of instances asbestos board barriers have been installed between wiring of adjacent bench board panels. Such barriers serve to localize serious control trouble, and are a convenient mounting place for terminal boards.

Special care is being given to arrangement of switchboard equipment and wiring to eliminate congestion and provide a maximum of operating convenience and accessibility.

Circular benchboards have been used in the control rooms of several large stations. This type of construction usually involves extra expense, and must be justified by the benefit to be gained in any particular installation.

Terminal Rooms

In metropolitan stations from which large numbers of feeders are served, the multiplicity of control required has in some instances necessitated the use of terminal rooms directly beneath control switchboard rooms.

In the Hudson Avenue station of the Brooklyn Edison Company, now under construction, such a terminal room is provided. In this particular installation, conduits are of uniform size and come up through the floor in groups to steel terminal boxes located in a circle directly under the benchboard on the floor above. There is convenient access to all control and instrument wiring. Terminal rooms of this sort increase the over-all cost of the station where their use necessitates increase in cubic feet of building. If they can be fitted in without such increase in building cost, the over-all station cost should not be materially more because of their use. In stations where terminal rooms would have increased cost to an extent not justified by the benefits gained, the following method of construction has been used with satisfactory results. The floor underneath the benchboard itself has been dropped approximately three ft. All conduits terminate in a steel trench box below the

TABLE II

MOTORS AND CONTROL—WEYMOUTH POWER STATION
THE EDISON ELECTRIC ILLUMINATING CO. OF BOSTON

For	Manu-facturer	No.	Motor				Control
			H. P.	Volts	R. P. M.	Type	
Circulating Water Pumps	G. E. Co.	4	290	2200	360	S. R.	Hand operated non-automatic oil circuit breaker. Hand operated drum controller and resistors for 25% speed reduction. Contactor and resistance for automatic restarting and transferring from one source of power to another.
Condensate Pumps	"	4	100	2200	1200	F. T.	Hand operated non-automatic oil circuit breaker to throw the motor directly on the line.
Deaerator Hot Well Pumps	"	4	60	2200	1200	F. T.	Hand operated non-automatic oil circuit breaker to throw the motor directly on the line.
Dry Vacuum Pumps	"	2	60	550	120	Syn.	Automatic contactor panel for throwing motor directly on the line. Permits transferring from one source of power to another but does not provide for automatic restarting.
425 lb. Boiler Feed Pumps	"	3	300	2200	1800	S. R.	Hand operated non-automatic oil circuit breaker. Contactor panel in secondary circuit controlled by master switch and drum controller operated by Ruggles-Klingemann regulator to give 20% speed reduction in five steps with automatic regulation at each step. Provides for automatic restarting and transferring from one source of power to another.
1200 lb. Boiler Feed Pump	"	1	350	2200	3600	S. R.	Hand operated non-automatic oil circuit breaker. Contactor panel in secondary circuit controlled by master switch and drum controller operated by Ruggles-Klingemann regulator to give 40% speed reduction in four steps with automatic regulation at each step. Provides for automatic restarting and transferring from one source of power to another.
Forced Draft Fans	"	4	135	2200	1200	B. T. S.	See text.
Induced " "	{ "	4	100	2200	600	S. R.	" "
	"	4	225	2200	900	S. R.	
Emergency Raw Water Pumps	"	2	50	2200	1800	F. T.	Solenoid operated, non-automatic oil circuit breaker with float switch or push button control.
" Dist. " "	"	2	40	2200	1800	F. T.	Solenoid operated, non-automatic oil circuit breaker with float switch or push button control.
Ash Quenching Pump	"	1	50	2200	1800	F. T.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
200 kw. Exciters	"	2	300	2200	1200	F. T.	Hand operated non-automatic compensator with external switches.
250 " "	"	1	370	2200	1200	F. T.	Hand operated non-automatic compensator with external switches.
Fire Pump	"	1	150	2200	1800	F. T.	Hand operated non-automatic compensator with external switches.
Air Compressor	"	1	106	2200	257	Syn.	Hand operated compensator with external switches with undervoltage release and field protective contactor.
Stokers	"	16	5	550	1650	B. T. A.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line. Pilot motor for shifting brushes for speed variation controlled by push button or Bailey combustion control system. Provides for automatic restarting and transferring from one source of power to another.
Clinker Grinders	West.	8	3	550	600	S. C.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Station Service Pump	G. E. Co.	1	10	550	1800	S. C.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Heater Drip Pumps	"	2	10	550	1200	S. C.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Evaporator Feed Pumps	"	2	15	550		F. T.-P. C.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Condenser Tube Wash Pump	"	1	15	550	900	F. T.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Auxiliary Cooler Pumps	"	2	25	550	1800	F. T.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
10 kw. Control M. G. Sets	"	4	20	550	1200	F. T.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
25 " Lighting " "	"	3	40	550	1200	F. T.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
High Heat Level Cond. Pump	"	1	7½	550	1800	S. C.	Hand operated non-automatic oil circuit breaker to throw motor directly on the line.
Evaporator Service Pumps	"	2	3	550	1800	S. C.	Magnetic switch with float switch or push button control.
Sump Pumps	Louis Allis	1	5	550	1800	S. C.	Float switch.
Bilge Pumps	" "	2	5	550	1800	S. C.	" "

TABLE II—*Continued*

For	Manufacturer	No.	Motor H. P.	Motor Volts	Motor R. P. M.	Motor Type	Control
Intake screen	G. E. Co.	1	7½	550	1200	S. C.	Non-automatic compensator.
110 ton crane	"			550			
20 " "	"			550			
5 " "	"			550			
Office Bay Pass. Elevator	Otis	1	15	550		S. R.	
Power House Freight Elevator	"	1	13	550		S. R.	
Switch House Pass. "	"	1	20	550		S. R.	
" " Freight "	"	1	13	550		S. R.	
Coal Larries	G. E. Co.	2	7½	550		S. R.	
Coal Breaker	West.	1	150	550	450	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
Conveyor "A"	"	1	100	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
" "B"	"	1	25	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
" "C"	"	1	125	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
" "D"	"	1	20	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
" "E"	"	1	20	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
" "F"	"	1	20	550	900	S. R.	Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
Coal Unloading Towers	"	2		550			Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
Coal Stock & Reclaiming Bridge	"	1		550			Hand operated oil circuit breaker with undervoltage release. Drum controller with starting resistance.
Misc. Vent. Fans, Heating Pumps, Oil Pumps				550		S. C.	Hand operated non-automatic oil circuit breakers to throw motor directly on the line.

S. R. —Slip Ring
S. C. —Squirrel Cage
F. T. —Double Squirrel Cage
F. T.-P. C.—Double Squirrel Cage, Pole Changing
Syn. —Synchronous
B. T. S. —Brush Shifting varying Speed
B. T. A. —Brush Shifting adjustable Speed

benchboard. Ample room is provided for all connections and terminal boards, and workmen can stand erect in the pit below each panel. Thus, repairs and changes in connections can be made almost as conveniently as in a terminal room. The question of whether or not a terminal room should be installed must be settled for each particular power station on the basis of the cost involved and the benefit to be gained.

Bus Structures

Practically all of the larger metropolitan companies have adopted, in their new stations, the isolated phase arrangement of switching equipment. This form of construction has been almost universally used where large numbers of feeders are supplied directly from the power station buses. With the continued increase in capacity of generating stations, it has become necessary to reduce the hazard of bus short circuit in every way possible.

The isolated phase scheme of construction has eliminated in some instances the conventional bus structure. The need of a totally enclosed compartment for the bus becomes of secondary importance. In many cases busses have been run entirely in the open. There are several companies that prefer to enclose the bus in the usual manner, and use through bushings for making connections to the bus.

Concrete or brick bus structures for auxiliary circuits are in many instances being eliminated by the use of truck type circuit breakers.

It should not be assumed that three-phase bus construction is obsolete for large stations or that it cannot be safely used where special attention is given to insurance against short circuit.

Where three phase bus construction is used, it has been found important to eliminate the passage of gases from one compartment to another in the case of breakdown to ground. All inspection openings in bus structures are enclosed by means of hinged or removable doors, and where conductors pass from one compartment to another through bushings, closure of the air passage is effected by various methods. In this way, with station neutrals grounded through resistance and all structures equipped with adequate grounding buses, disturbances on one phase, thus limited in severity, have little opportunity to involve the other phases and cause a bus short circuit.

The design of isolated phase equipment is now well

through the development stage, and with the operating records of such equipment in service, which will be available within the next few years, a definite value can be placed upon the protection against short circuits which results from this type of construction.

The question whether isolated phase or three-phase bus construction should be used, must be solved in each particular case on the basis of the conditions to be met.

Turbo-Generator Units

The future of the electrical industry is now so dependent on steam turbo-generator development that advancement and improvement in design and construction of this type of prime mover is of extreme importance in every detail affecting the reliability of operation, the efficiency and the initial cost of the unit.

Improvements made and the most notable advances incorporated in the designs of several large power stations now under construction involve the use of higher steam pressures and temperatures, inter-stage reheating of steam, and stage steam bleeding.

The movement in the direction of higher steam pressures was initiated in 1917 at the North Tees power station in England where a gage pressure of 475 lb. per sq. in. and total steam temperature of 725 deg. fahr. was adopted. Inter-stage reheating was contemplated but was abandoned because of a few necessary modifications in turbine design and detail of piping which could not be undertaken during the war period. These improvements, however, have since been made. Although no consistent operating results are as yet available at this plant, the possibility and practicability of satisfactory operation at pressures of 500 lb. and 700 deg. fahr. have been demonstrated. A number of minor difficulties has been overcome and a great deal of valuable data and experience added to our knowledge of the use of higher steam pressures, all of which do honor to the pioneers who had courage enough to blaze a new trail in steam power plant practise.

On the other hand, very little has been added to our knowledge of the properties of steam at high pressures, but the innovations adopted indicate clearly that an appreciable gain in economy should be expected in returning heat to the boilers, through stage bleeding, instead of carrying it out to the condensers.

Steam turbine designers do not anticipate any particular difficulty in producing machines adapted for pressures of 1200 or 1500 lb. per sq. inch. For these high pressures two or more cylinder machines will be used, the high pressure cylinder being small and operating with as good a factor of safety as the lower pressure cylinders.

Regarding steam temperatures, the limitations of strength of metals now available do not permit the use of temperatures in excess of 750 deg. fahr. Research for metals capable of safely withstanding higher temperatures for turbines, as well as for valves and fittings, is being conducted.

The rapid growth of turbo-generators to the sizes now being installed indicates the trend of development of the industry in general. Single cylinder units of 30,000 kw. have now become well standardized, and in answer to the demand for still larger sizes, 50,000-kw. turbo-generators of the single-cylinder type have been developed, and seem to be the next step indicated in size of single-cylinder units.

Considerable progress has been made in the last four years in turbine design and construction with a view to securing increased efficiency and reliability of operation, and, at the same time, to improving the steam cycle conditions. More stringent steam and vacuum conditions, in order to increase the heat-drop between the throttle valve and the exhaust outlet, have brought about many changes in turbine design and construction as well as in the selection and arrangement of plant equipment and layout.

With the increasing demand for larger sized units, and with the tendencies toward higher steam pressures and temperatures, there are indications that new designs will be adopted involving the sub-division of the turbine into two or more cylinders and shafts.

Single barrel units of 35,000 kw. and tandem compound units of 60,000 kw., both types for operation at 550 lb. and 750 deg. fahr. are now being installed; 2600-kw. and 4000-kw. turbines, designed for a steam pressure of 1000 and 1200 lb., are under construction. These machines are an entirely new departure and involve special boiler equipment and piping arrangement. The turbines themselves, however, are simple in design and present no obstacles to the ultimate success of the system adopted.

Tandem compound units with single shaft, both single- and double-flow types, in sizes ranging from 30,000 to 60,000-kw. have been successfully developed for speeds higher than for units of the single-cylinder type. Designs of large units with two shafts and three cylinders have been completed which reduce the number of alternators to only two.

Some increase in efficiency may be expected from these new designs or turbines, and the multi-cylinder arrangement will greatly simplify the application of steam reheating between high- and lower-pressure cylinders. The reheating cycle seems to be, of necessity, a feature of increasing importance, depending on the steam pressure adopted.

Quite a number of important problems remain to be completely and satisfactorily solved as further advance is made in the development of steam turbines, especially now that more severe operating conditions are imposed. Among these problems are; suitable material for blading and means to safeguard its reliability. The lack of an entirely satisfactory material that is sufficiently mechanically strong, that maintains its strength at high temperatures, that is reasonably cheap, easily machined, resistant to corrosion and erosion, and, most important of all, thoroughly reliable, is one of the limiting

factors in the designs for large outputs and high speeds. Chemical corrosion, due to air dissolved in the feed water, is now almost eliminated by the use of deaerators, evaporators and close circulation systems; but erosion is becoming more serious, since the present limit of safe initial steam temperature has been practically reached, and therefore, progress toward high initial pressures must result in larger moisture percentages in the last stages.

Next in importance are the questions of blade fastening to the wheels or barrels, the lacing or shrouding, the balancing of rotors, the keeping of length of blades, blade speeds and stresses within reasonably safe limits, while reducing and leaving losses to a minimum. To reduce the leaving losses, several methods have been recently developed, such as the "duplicate exhaust" and the "multi-exhaust" with directing steam vanes.

The bleeding of steam from one or more of the turbines stages for feed water heating has been advocated by turbine manufacturers for some time, but it is only recently that power station engineers have considered the subject with the interest which it deserves.

Stage bleeding is applied for the purpose of improving the efficiency of the heat cycle as a whole, but since this improvement is due in part to the effect of bleeding on the performance of the turbine unit, the subject is properly mentioned at this point. The diversion of a considerable fraction of the input steam at intermediate stages reduces the leaving losses and the effects of choking in the lower stages; a smaller quantity of steam is left to be condensed; the vacuum is improved, and less heat is passed on to the condenser.

To obtain the full advantage of stage bleeding, normal operation of auxiliaries must be almost entirely electrical.

The first commercial equipment which includes a mercury boiler and turbine exhausting into a condenser boiler which in turn generates steam for an existing steam turbine station, was put in service in the fall of 1923. The results which have been obtained confirm experimental tests and there is every reason to believe that this development will be of great value in reconstructing existing stations.

Generators

Improvements in design and construction of the generator have kept pace with those of the steam turbine. These simultaneous advances have made possible the supply of the demand for larger, more reliable and economical units. The additions made in 1923 to the generating capacity of the steam-electric plants in the United States totalled over 2,000,000 kv-a.

The progress made in recent designs is the result of efforts directed towards reducing the mechanical and electrical weakness of older machines, improving the ventilation, thus permitting the use of longer rotors and the production of generators of larger capacity. As to reliability, marked progress has been made in the insulation, both as to class of material and its application. There are more effective methods of holding the rotor coils, and bracing and clamping the stator end connections, thus increasing the reliability of the windings under stresses of short circuits or system disturbances.

As to size of generators, 62,500-kv-a. steam driven units are now being produced. The largest units built, however, are water-wheel generators having a rating of 65,000-kv-a., 12,000-volt, 25-cycle, 107 rev. per min.

The closed system of generator cooling, which has been installed in a number of large stations during the year, has many points of advantage. The air, having once been cleaned by the washer, filter or other device, remains clean indefinitely, reducing the deposit-forming material circulated through the windings practically to zero. By the closed system also, relatively little oxygen is available to support combustion, and the fire hazard, which has been quite serious with the open system, is greatly reduced.

In line with the general efforts to improve the economy of generating stations, some of the newer installations are equipped to cool the air discharged from the generators, using condensate as the cooling medium, thus retaining the heat lost in the generators.

With the trend in new generating stations towards stage bleeding for feed water heating, the use of electric driven auxiliaries is indicated for normal operation as to obtain the greatest advantage. To supply the essential auxiliaries, consideration has been given to the use of an auxiliary generator, connected to and driven directly from the shaft of the main unit. This method combines high reliability and economy. Several such installations with a-c. auxiliary generators and one installation with d-c. auxiliary generator are definitely planned.

Power Station Ventilation

With the growth in the size of power stations, the problems of ventilation, heating and lighting have increased and are receiving special consideration by both the architect and designing engineer.

Ventilation in the large modern power station presents entirely new and different problems involving the provision of features which were considered of trifling importance in the smaller power stations of the past.

Today the problem of ventilation involves the satisfaction of three main requirements:

1. Supply and movement of air for respiration.
2. Supply and movement of air for cooling apparatus.
3. Supply of air for combustion purposes.

These requirements must be satisfied at all times and under wide fluctuation of climate conditions. The conditions vary according to the geographic location and operation of the power station; *i.e.*, whether the station is continuously operated or subject to occasional shutdowns.

Ventilation and daylight illumination are closely allied, as well as problems of heating, where such requirements are necessary.

The first requirement; *i.e.*, providing a supply and movement of air for respiration, fortunately, offers no serious difficulty in the power station where large spaces are generally available and which, because of the relatively few men to be accommodated, do not require an active movement of air. In the modern power station however, dependence can no longer be placed on securing an adequate supply of fresh air for respiration through leakage around windows and doors. Other and more substantial means of ventilation must be provided. These, as far as possible, should depend on natural effects rather than artificial circulation of air, except where it is absolutely necessary to introduce purifying or conditioning devices.

The second requirement,—the provision of air movement for the cooling of apparatus—is a large item in power station design. This problem involves the absorption and dissipation of heat units generated and radiated by the station equipment. Future improvements, however, will doubtless serve to recover these losses and return them to the system.

At the present time, it is necessary to provide a sufficient volume of cool air for the removal of these heat units, not only from the electrical apparatus but also from steam and hot water piping and other apparatus.

One of the problems which has been practically solved is the prevention of condensation in the turbine room, and satisfactorily solved, too, under the very much more difficult conditions found in dye houses and paper mills, where tons of water are evaporated each day by the processing machinery used in these plants. Turbine room conditions, fortunately, are not so serious and by proper insulation of the roof structure and ventilation, it is possible to maintain the room atmosphere below its dew point, thereby preventing the condensation of warm, moisture-laden air which is found in the atmosphere of the turbine room.

The last requirement involves the supply of a large volume of air for combustion. It has been found in cases where no provision was made to meet this need that during the winter months the air supply for combustion was entirely insufficient. This condition would not exist in summer when the air could be admitted through open doors and windows. With the increased size of boilers, and with the tendency toward air preheating, this problem becomes one of great importance and requires special study for both the forced and induced draft. Ideal conditions will be met when the warm air is taken from the atmosphere of the boiler room and returned to the furnace, thus accomplishing the dual function of ventilation and heat-loss recovery.

Lightning Arresters

The Protective Devices Committee of the Institute has an efficient subcommittee actively at work on lightning arresters, and its report will thoroughly cover the ground in its technical aspects. A brief survey of the field, however, from the viewpoint of some of the manufacturers may be appropriate here in considerations of power station design. The manufacturers are of the opinion that they are furnishing apparatus which is quite effective, if properly installed and used; that their studies now under way will result in improvement, but they all point out the fact that a great deal depends upon intelligent co-operation on the part of the users.

Arcing grounds on non-grounded circuits, over-dynamic voltage, such as is caused by overspeeding of waterwheel generators, and faulty grounding of lightning arresters, are some of the causes of failures over which the manufacturers have no control. Doubtless, these sources of trouble will largely disappear when the users become aware of their seriousness and their undesirable effect upon an important piece of protective apparatus.

Two of the large manufacturing companies have testing equipment using the so-called lightning generator of Steinmetz. These devices afford excellent opportunities for studying the action of arresters under artificial lightning disturbances of an impulsive character.

Briefly, the lightning generator has revolutionized the testing of lightning arresters and their performance in actual service can be closely predicted. This fact should be emphasized and operating companies should more fully realize what fundamental characteristics a lightning arrester should possess and that these characteristics can now be determined in the laboratory. It is not essential to wait for data on hundreds of lightning arresters over a period of years before the true value of any particular arrester can be determined.

The lightning generator, however, shows chiefly the effect of the impedence of arresters to high current impulse of very short duration. They do not show the effect on arresters of all of the disturbance that may occur on transmission lines or distribution circuits. That disturbances other than impulses of extremely short duration do exist, is hardly a matter of doubt; they should be carefully studied. An arrester may be satisfactory from the standpoint of laboratory tests in discharging impulses and yet may be vulnerable to disturbances having an appreciable time element. At present this can be determined only by several years of service operation.

The real present need of the manufacturer for future progress with arresters is, as he says, not so much in actual apparatus development as in getting more specific and definite data on conditions to be met in service. He needs to know much more definitely not only what the surge voltages are, in magnitude, duration and frequency of oscillation and of occurrence, but also to what values these surge voltages may be reduced before reaching the apparatus to be protected. It is also necessary, since economics plays an important part

in the choice and use of arresters, to evaluate less than full protection in terms of average yearly injury to apparatus.

With this sort of information available, he believes he can add to the assurance that the characteristics of present designs actually meet conditions of service as fully as is now believed, and moreover that he can apply arresters with greater precision and with fuller assurance of obtaining the desired results.

Transformers

All the manufacturing companies disclaim any new radical changes in the design of transformers during the past year. A few things, however, have been done for the sake of protecting the transformer in case of breakdown. Changes have been made in construction methods and some companies still disagree in regard to polarity of distribution transformers.

The problem of protection of transformers from explosions has been attacked in various ways: a manufacturer placed on the market last year an "Inertaire" transformer which is claimed to be practically immune to explosions or internal fire. This is accomplished by equipping the transformer with an air tight cover and connecting the free space between the top of the oil and cover with an inertaire respirator which deoxidizes the air which passes through it. This respirator is filled with a substance which is said to be able to deoxidize the air as rapidly as it enters, allowing only nitrogen, an inert gas, to pass into the transformer.

The idea of using an inert gas in transformers to prevent explosions is not new; another manufacturer used $C\,O_2$ gas in transformers constructed several years ago, but later did away with the practice, developing instead the oil conservator.

So far as is known, there has been no trouble developed from the use of the "Inertaire" attachment. The following criticism might be offered, however. Since the deoxidation of the air is accomplished by chemical absorption of the oxygen by the compound in the respirator it follows that sooner or later the compound will depend upon the rate at which the transformer "breathes." The rate at which a transformer will "breathe" will depend upon varying load conditions, change of surrounding temperature, and seasonal changes. Two transformers alike in every respect, but working under different conditions, even on the same system, would have different rates at which the deoxidizing compound would be dissipated. This would make necessary frequent inspection of the compound in the respirators and irregular renewals. If a transformer were allowed to go a few days beyond the point of complete dissipation of the compound it would fill itself with ordinary air, which would mix with the gases from the oil and form an explosive mixture.

This device, however, offers a protection to the oil since it minimizes surface oxidation of the oil.

Winding of Disk Coils for Core-Type Transformers. During the past year one of the principal manufacturers developed a new method of winding flat disk coils for core-type transformers. This method makes it possible to wind a complete stack of either primary or secondary disk coils with one or more continuous conductors. The first coil in a stack is wound from the outside to the inside and so on until the complete stack is wound. There are two distinct advantages gained by this method. One is the elimination of all connections between coils and thereby eliminating the possibility of trouble arising from poorly soldered joints. The second benefit comes from lessening the handling of the coils, which reduces the possibility of injury to the insulation and insures better electrical conditions. Another advantage is that the new method speeds up production, which is to the advantage of the user.

Polarity of Transformers. Since 1922, when the N. E. L. A. transformer standards providing for standard polarity for single-phase transformers were adopted and put into use by the two largest manufacturers, some confusion in overhead distribution systems has been caused by diverse practise on the part of some of the smaller manufacturers. It is highly desirable that there should be uniformity of manufacturing practise in this respect.

Temperature Indicators

Several manufacturers were requested to supply information as to the progress made in the past year in the field of "Temperature Indicators." That no radical changes have occurred was admitted by most of them. In general, the progress consists in the addition of refinements or improvements by slight changes of construction to standard equipment.

One manufacturer has improved the optical system in his radiation pyrometer so that better accuracy can be obtained when used on small objects. Another has placed in production a Precision Portable Potentiometer for use with thermocouples, one scale division of which, is equivalent to approximately 1 deg. fahr. when used with an iron constantan thermocouple. Some minor improvements also have been added to instruments actuated by change of resistance of the bulb unit and also those actuated by expansion of gas contained in the bulb unit. Another manufacturer, in development of an instrument for indicating or recording temperatures at a distance, has reached the point where the instrument has been shown to be thoroughly practicable but he is not ready as yet to disclose the principle of operation or the type of construction.

Some tendency is evidenced to apply to commercial thermoelectric pyrometers and resistance thermometers, principles perhaps never so used before, although known and used in an experimental way twenty-five years or more ago.

Electric Drive in Fuel Preparation

Much interest was exhibited by the various public service and other companies, including some of the

TABLE III

No. Plant Reporting	A	B	C	D	E
1	Crushers bucket elevators, belt conveyors	6 motors, total 210 h. p., G. E. and Wagner 3-phase 25-cycle	1923 tons 187,002	Per ton 2.9 kw-hr.	Received by rail, 2 locomotive cranes, 2 locomotives, and 2 gondolars, used in handling storage.
2	100% electric drive	21 motors, total 1175 h. p. 3-phase 60-cycle	362,800	1.38 kw-hr.	Received by barges, clam shell bucket to crushers, conveying belts to bunkers, by rail for storage, clam shell bucket and crane.
3	100% electric drive	8 motors, total 175 h. p. a-c.	146,000	.65 kw-hr.	Received by rail, dumped to hopper, pan conveyor to crusher, inc. belt conveyor to top boiler room. Horizontal belt conveyor to bunkers, bridge crane for storage.
4	100% electric drive	6 motors, total 160 h. p., d-c.	146,000	Not given	Received by rail, dumped to pit, bridge crane with crushers. Transfer cars to coal bunkers.
5	100% electric drive	8 motors, total 145 h. p.	233,875	2.8 kw. (1) 5.7 kw. (2)	Rail-bridge crane to crushers from storage cars to crushers by winches, crushers to belt conveyors and bucket conveyors.
6	100% electric drive	11 motors, total 1339 G. E. Allis - Chalmers West. 3-phase 25-cycle	407,412	1.059 kw-hr.	Coaling, tower from scows at dock to crushers, 4 toncars to bunkers, aerial cableway for storage.
7 Pulvzd. anthracite	100% electric drive	30 motors, total 1055 h. p. 3-Phase 60-cycle	63,352 Anthracite slush	See E	Recovery from storage pile to boiler bins, inc. drying, pulverizing, conveying 25.93 kv-hr. per ton.
8 2 plants combined	100% electric drive	22 motors, total 710 h. p. 2- and 3-phase 60-cycle	142,663	2.5 kw-hr.	Barge to coal tower, to coal car, to crusher by locomotive, to coal conveyors, to bunker bins, Gantry crane for storage handling.
9	100% electric drive	19 motors, total 677 h. p. a-c. 60-cycle 440-volt	479,750	No record	By rail to storage by locomotive crane, by cars to card umper to shaking feeder, to conveyor belt to breakers, to crushers, to bucket conveyor, to boiler bunkers.
10 Pulverized bituminous. Not in operation	100% electric drive	13 motors, total 419 h. p. 3-phase 60-cycle 440-volt	Max. capacity 105,000 12 tons per hr.	Not operating under con-struction	Rail, track scale, to track hopper, skip hoist to crusher, to dryers, to pulverizers, to cyclones, to screw conveyor to boiler bins.
11 2 plants combined	1-50%, 1-100% electric drive	31 motors, total 1258 h. p. a-c. & d-c. motor	780,000	1.0 kw-hr.	Barges to coal tower to receiving hopper, to crushers, to weighing hoppers, to belt conveyors to bunker bins in boiler room.
12	100% electric drive	51 motors, total 2750 h. p. a-c. squirrel-cage and slip ring	300,000	3.0 kw-hr.	Steamer movable towers, to crushers, to cable cars, to station bunkers, or to storage lot. From latter reclaimed by skip hoist. From bunkers to weigh lorries to furnace hoppers.
13 2 plants combined	100% electric drive	No data	(1) 135,000 (2) 60,000	.75 kw-hr.	Cars to track hopper, to crushers, bucket conveyor belts, distributed to bunker bins.
14	100% electric drive	18 motors, total 837 h. p. a-c. 230 & 2200-volt	482,335	.43 kw-hr.	Cars to pits, conveyor to crusher, to carriers elevated above boilers, cross conveyor belts, distributed to bunker bins.
15	100% electric drive	9 motors, total 590 h. p. a-c. 220 & 2200-volt	108,797	.6175 kw-hr.	Ditto
16 Pulverized bituminous under construction	100% electric drive	32 motors, total 1558 h. p. a-c. 230 & 2200-volt	Pulvd. coal est. 78,126 7 months 1924	See E	Do.-Crushed coal, to coal preparation house, gravity to dryers, to pulverizer mills, then by Fuller-Kinyon Pumping System to boiler pulverized coal bins. All power estimated 22½ kw-hr. per ton.
17	100% electric drive	13 motors, total 1115 h. p. a-c. 2- & 3-phase, 60-cycle	276,032	.755 kw-hr.	Barge to crusher in tower, conveyor to top of building, cross conveyor to boiler bunkers, coal storage by locomotive cranes, capacity 3000 tons per day.
18	100% electric drive	9 motors, total 1060 h. p. 2-phase a-c. 60-cycle	174,408	.954 kw-hr.	Barge to crusher in tower, cable road to boiler bunkers. Coal storage by locomotive crane. Capacity 1000 tons per day.

TABLE III—*Continued*

No. Plant Reporting	A	B	C	D	E
19	90% electric drive	16 motors, total 900 h. p. 2-phase a-c. 60-cycle	249,456	1.00 kw-hr.	Ditto but coal is crushed twice.
20	50% electric drive 50% steam	6 motors 145 h. p. steam storage locomotive yard and 2 locomotive cranes	166,250	Not quoted	Rail-cars handled by steam locomotive, dump to hopper-hoist by movable tower to roof, to crushers, to boiler room. Storage by 2 locomotive cranes.
21 2 stations reporting	100% electric drive	6 motors 205 h. p. d-c. (no unloading inc.)	438,000 365,000	0.25 kw-hr. 0.31 kw-hr.	Barge-coal towers to crushers, to cable road belt conveyor, to boiler bunkers.
22	100% electric drive	2—700 h. p. m-g. sets towers, 24 motors, 1748 h. p. d-c. & a-c. 3-phase 60-cycle	Est. 226,000 1924	1.08 kw-hr.	Barge, 2 coal towers to crushers, sampled, to cars automatically operated, to boiler bunkers. Storage 50,000 tons—Staten Island, for emergency.
23	Hoisting by steam. Balance 50% electric drive	10 motors 140 h. p. d-c. 230 & 125-volt	336,000	No hoisting .161 kw-hr.	Barge, steam hoists to crushers, to electric driven coal cars, to boiler bunker bins. Storage mentioned No. 22 for this plant also.
24	Hoisting by steam. Balance 50% electric drive.	11 motors 161 h. p. d-c. 115 & 220-volt	197,000	No hoisting .161 kw-hr.	Ditto. Inc. transfer some coal by belt conveyor to boiler bunkers.
25	40% electric drive	3 motors 27 h. p. a-c. 60-cycle 3-phase	7,350	0.90 kw-hr.	Rail to crusher hopper, conveyor to bunker bins, locomotive crane for storage.
26	100% electric drive	3 motors 45 h. p. a-c. 3-phase 60-cycle	40,411	Est. 4.5 kw-hr.	Rail to derrick to crusher, to belt conveyors to bunker bins.
27	100% electric drive except for storage-locomotive crane	4 motors 150 h. p. a-c. 3-phase 60-cycle	50,400	.8 kw-hr.	Rail, skip hoist to crusher above bunker bins, belt conveyor to latter. Locomotive crane for storage.
28	100% electric drive	10 motors 480 h. p. a-c. 3-phase 60-cycle 2200 & 440-volt	240,000	.52 kw-hr.	Direct from mine, weigh baskets, to pan feeders, to crushers, to inclined belt conveyor, to bunkers. Drag conveyors for storage also locomotive crane. 71,000 tons storage.
29 Pulverized coal	100% electric drive coal from bunker bins	4 motors 300 h. p. a-c. 3-phase 220-volt	Capacity 2 mills, 10 tons hr. 36,000 tons	See E Pulverized coal	Coal from bunker direct to pulverized coal mills, to dryer, to cyclone, to burner feeders, 27 kw-hr. per ton, coal contains some bone and silica.
30	95% electric drive pulverized coal. Dryer fans by steam	22 motors 477 h. p. a-c. 440-volt 3-phase, induction	50,000 Steam heating operating 8 months per year	See E Pulverized coal	Electric cars to raw coal bunker, drying, conveying, pulverizing, conveying to boiler bunker bins, 22.3 kw-hr. Emergency storage several miles distant. Locomotive crane, clam shell bucket.
31	100% electric drive	14 motors 578 h. p. a-c. & d-c. 440 & 230-volt	540,000	.55 kw-hr.	Rail to bins, to crushers, bucket elevators, belt conveyors, to bunker bins. Gantry crane for coal storage.
32	100% electric drive	5 motors 105 h. p. a-c. 3-phase 220-volt	91,250	1.4 kw-hr.	Rail to hopper, to crusher, belt conveyor, to bucket elevator, to top of bunker scraper conveyor to bunkers. Storage-crane-clam shell bucket.
33	Unloading steam driven towers. Balance 100% electric	1495 h. p. 37 motors d-c. & a-c. 550-volt	389,623	1.734	Barge, belt conveyor to crushers, conveying belt to bunkers in boiler room. Storage from barge conveyor belts to field.
34	100% electric drive	11 motors 183 h. p. a-c. 60-cycle 3-phase 550-volt	276,000	No data	Rail, bridge crane, belt conveyor, bucket elevator to belt conveyor to bunker bins, slack coal, do not use crusher. Storage by steam, or electric cranes.
35	100% electric drive	5 motors 107 h. p. a-c. 3-phase 60-cycle 220-volt	75,000	0.6 kw-hr.	Rail to crusher, belt conveyor to bucket elevator, to scraper, conveyor to boiler bins. Storage by horizontal boom crane.

largest and most efficient plants in the country, in submitting to the Committee the accompanying tabulated data, the various plants being listed for obvious reasons by number only.

The plants reported in the tabulation had a total coal consumption for the year 1923 of 6,767,528 tons.

The average power per ton of coal handled is 0.98 kw-hr.

The total horse power installed averages 0.0019 h. p. per ton.

The following key is to be used with the foregoing data table:

A. Extent or use of electric drive in coal preparation
B. Number and size and characteristics of motors
C. Annual tonnage handled
D. Estimated kilowatt-hours per ton
E. System used in coal handling and storage equipment.

Automatic Equipment

The general trend in generating station design for the year 1923 has been to lean strongly toward automatic operation of apparatus where practical, particularly so where a personal hazard might otherwise be involved.

The tendency has been toward:

A general increase in the size of automatic or remote-controlled hydroelectric generating stations; the elimination of the human element, by making automatic the sequence of operations in connection with high-tension switching, where a failure to follow the proper sequence might result in a serious hazard or damage to equipment;

the electrification of station auxiliaries with automatic restarting or remote control;

the providing of the system operator with automatic line and system load indication, for better supervision and control.

A considerable saving has been shown in the past by automatic operation of small hydroelectric generating stations, but the tendency now is toward making wholly automatic or remote-controlled stations of even larger capacity. Illustrations of this are Sprite Creek Station of the Adirondack Power Company, where a 7500 kv-a. generating station is automatically controlled, and an installation of three 1750 kv-a. units of the Wisconsin Valley Electric Company. There are some 60 installations of this kind with nearly 100 generating units.

While larger steam generating stations are not being made wholly automatic, every year records the addition of more automatic equipment. In the broader sense, where automatic operation includes interlocking to prevent a wrong sequence of operations, the advance is more marked, as illustrated in the Weymouth Station of the Edison Electric Illuminating Company of Boston, the Commonwealth Edison Company's Calumet Station at Chicago, and the Cahokia Station at St. Louis, where the disconnectors on the line-switches are interlocked with the oil-switch, to prevent wrong sequent operation. In some cases the disconnectors are automatically operated by the oil switch mechanism.

Station auxiliary apparatus is being electrified and the operation effected with remote automatic control. One feature of recent design is the automatic restarting of the essential auxiliary motors when power is restored after a shut-down.

Some of the larger systems are giving serious consideration to the question of providing the system operator with automatic indications of the system line and load conditions by means of automatic totalizing meters to indicate the load on the various generating stations, together with the total system load.

A further advance in automatic operation is the automatic indication at the system dispatcher's office of the open or closed position of the line-switches, and some thought has been given to the question of giving the system dispatcher control over some line-switching, independently of the station operator, so that the system dispatcher is not only a general supervisor of operations but has independent control of the general power system as well.

The manufacturers seem to be putting forth every effort to make their systems of remote and automatic control more reliable, so that the operating companies will have more confidence in this type of equipment and will undoubtedly find further use for it.

Nicholas Stahl, *Chairman.*

The report concludes, with a complete bibliography of papers on the subject of power stations for the year, 1923-4.

(*To be continued*)

ELECTRICAL HAZARDS IN MINES

The use of open-type electrical equipment, which fails to safeguard against the transmission of sparks and flame to gaseous and dusty atmospheres in coal mines, constitutes a real menace to the American miner, according to the Department of the Interior. Records of the Bureau of Mines covering 26 coal mine disasters and fires due to unsafe electrical apparatus show the loss of 500 human lives in addition to great damage to property. An open-type electric coal drill used in a gaseous mine in West Virginia was the probable cause of the death of 27 miners, the Bureau points out. A half-safe type of electric coal-cutting machine used in a gaseous mine in Pennsylvania was probably the cause of the death of 36 men. An unapproved, unsafe type of flame safety lamp used in a gaseous and dusty mine in Utah was the alleged cause of the death of 171 men. All three disasters happened within the past six months, and would seem to have been avoidable if proper equipment had been used.

Electric current can cause accidents in coal mines in five general ways: By shock to persons; by igniting powder; by igniting gas; by igniting coal dust; and by setting fire to inflammable material such as timber and coal. A great many accidents from these causes are preventable if proper care is taken. Most of the accidents caused by sparks and flashes from electrical apparatus would not take place if electrical equipment tested and formally approved by the Bureau of Mines was used. So far as known, up to the present time, no disasters have been caused by sparks or flashes from equipment having the Bureau's approval.

Discussion at Midwinter Convention

ECONOMICS AND LIMITATIONS OF THE SUPER TRANSMISSION SYSTEM[1]
(THOMAS)
SOME THEORETICAL CONSIDERATION OF POWER TRANSMISSION[2]
(FORTESCUE AND WAGNER)
POWER TRANSMISSION[3]
(HANKER)
POWER LIMITATIONS OF TRANSMISSION SYSTEMS[4]
(EVANS AND SELS)
EXPERIMENTAL ANALYSIS OF THE STABILITY AND POWER LIMITATIONS OF TRANSMISSION SYSTEMS[5]
(EVANS AND BERGVALL)
LIMITATIONS OF OUTPUT OF A POWER SYSTEM INVOLVING LONG TRANSMISSION LINES[6]
(SHAND)

F. G. Baum: The papers that have been presented so far are based on calculations made using the hyperbolic functions. On any transmission line of considerable length in which we apply voltage at one end, we immediately get some charging current near the station. That charging current tends to raise that voltage, and as we go along the line, each increment of the current tends to raise that voltage, and we have the rising characteristic of that transmission line.

However, if we are going to have a general power system, it is necessary, as far as I can see, that we have a practically constant transmission line.

If we are going to have constant voltage transmission, then you can see at once that the charging kv-a. per mile of line or hundred miles of line will be the same. That is, it is not a quantity then that is gradually changing as you proceed out from the station to the line, but every mile of line is a repetition of every other mile, so we have a straight line of relation of the charging line, if we maintain constant potential. That makes the attack of the problem very much simpler and you can use a simpler calculating device. The paper by Mr. Shand uses the old-time method of vector equations, which is correct so long as the charging kv-a. per unit length of line is constant, and that is the assumption we are starting out with.

Edward L. Moreland: The four papers which have been presented are interesting to anyone who is working on the problem of long-distance transmission—by long distance I mean distances of from 250 miles up to 500 miles or more.

Our office has for some time been working on a specific problem of this kind,—one of our clients having asked us about a year and a half ago to study for them the electrical and mechanical feasibility of transmitting a large block of power from Canada, a distance of approximately 500 miles. We made a preliminary report in October, 1922, that such a project is feasible, and have continued our investigations of the details since that time. Mr. Booth of our office has borne the brunt of this work. Professor Bush of the Massachusetts Institute of Technology has also aided in these studies and has worked with Mr. Booth in the development of the methods of analysis which we have applied to the problem.

In the course of our studies, we have also conferred from time to time with others who might be interested in problems of this kind, particularly with the authors of some of these papers and with the engineers in the research department of the General Electric Company, but we have apparently carried our analyses further than the authors of these papers.

1. A. I. E. E. JOURNAL, Vol. XLIII, 1924, January, p. 3.
2. A. I. E. E. JOURNAL, Vol. XLIII, 1924, February, p. 106 and April, p. 373.
3. A. I. E. E. JOURNAL, Vol. XLIII, 1924, January, p. 33.
4. A. I. E. E. JOURNAL, Vol. XLIII, 1924, January, p. 45.
5. A. I. E. E. JOURNAL, Vol. XLIII, 1924, April, p. 329.
6. A. I. E. E. JOURNAL, Vol. XLIII, 1924, March, p. 219.

There is a common point of weakness in the Thomas paper, the Evans and Bergvall paper, and the Fortescue and Wagner paper, namely, that all three make their analyses on steady-state conditions, and base their conclusions as to stability of operation and limitations of power on these analyses. The limitations are, however, not imposed wholly by steady-state conditions but also by transient conditions, and consequently analyses of steady-state conditions alone do not give a proper basis for conclusions. Before accurate conclusions can be drawn, analyses must be made taking into account the transient conditions produced by sudden changes in the load, including the effects of kinetic energy of rotating equipment connected to the system and the transient effects induced in the fields of synchronous apparatus connected to the line. Fortescue and Wagner discuss the transients in a general way but make no effort to calculate the effects, and their conclusions are based on the steady-state analysis.

Steady-state analysis is interesting only as a step in the complete analysis, but does not furnish a sound basis for drawing conclusions as to stability of the line or of power limitations.

Mr. Thomas bases his design upon steady-state analysis. This takes no account of the behavior of the synchronous condensers, or of the behavior of the system during load changes. A consideration of these matters soon shows that a 500-mile unsectionalized line is unsuitable for 100,000 kw. per circuit at 220 kv. normal terminal voltage. In lines of this length steady-state analysis is not sufficient, for the instability of the system is made apparent only by transient analysis involving the electrical and mechanical constants of the connected apparatus. Mr. Thomas uses a very large conductor, but our analysis has shown that stability under switching is not greatly affected by the size of conductor, within reasonable limits. The reason for these difficulties of stability lies in the fact that 220 kv. is inherently a low voltage for 500-mile transmission at 60 cycles per second.

Messrs. Evans and Bergvall point out the limitation that at a certain load the action of the regulators becomes indeterminate and produces instability. This again is based on an analysis which considers the performance of the system to be a succession of steady states. It, hence, applies at normal operating receiver voltage, but does not apply during fluctuations; for during fluctuations various factors, such as the kinetic energy of the rotating masses and the transients in condenser fields, come into play which are not considered at all in steady-state analysis. Their analysis, therefore, shows one limit to steady operation, but it gives no information about stability during switching. There is hence here no basis for general conclusions regarding the operation of a system where sudden load changes may occur due to switching. The tests made by Messrs. Evans and Bergvall are also limited to conditions of gradually applied load, for a motor-generator set cannot transfer its load to the system until it swings back in phase. This is clearly indicated by the oscillograph record shown in one of their charts. The behavior for a suddenly applied load is very different, as will be shown.

The chart given herewith (Fig. 1) shows the power curves for a 250-mile, single-section, 220-kv., 60-cycle line, with four 20,000-kv-a. condensers at the receiving end. The locus of steady-state Tirrill instability is also shown. Considering steady-state conditions alone, the chart shows that at 100 per cent normal voltage the line can deliver 190,000 kw. This would mean that if the line were delivering 100,000 kw., the load could be increased by 90,000 kw. without pulling the line out of step. This would be true if the load were gradually increased so that the regulators had time to function and keep the voltage constant.

If, however, the load is suddenly increased, the conditions are very different due to the transient effects. The heavy wave line indicates the cycle of voltage conditions through which the

system will pass if the load is suddenly increased from 100,000 kw. to 140,000 kw. The complete cycle has not been plotted but the oscillations will center on the 140,000-kw. line and ultimately come back to it. It will be observed that the first swing carried the system into the region of apparent Tirrill instability and safely out again; this is again due to transient effects. If, however, the load is suddenly increased from 100,000 kw. to 150,000 kw., the voltage will continue to drop on the first swing and will not recover, but the line will break out of step.

The significance of this chart is that it shows that steady-state analysis alone would have made it appear that 90,000 kw. could be successfully switched onto a line already carrying 100,000 kw.; whereas, in fact, less than 50,000 kw. could be suddenly switched onto it without breaking the system apart. This clearly shows that steady-state analysis alone does not give results sufficiently accurate to warrant using such analyses as a basis for drawing conclusions.

Discussions presented by Mr. Booth and Professor Bush give some specific illustrations of complete analyses under transient conditions.

The studies made by the authors are of great interest and the data from their tests form a valuable contribution to the knowledge available on this subject, but the conclusions drawn

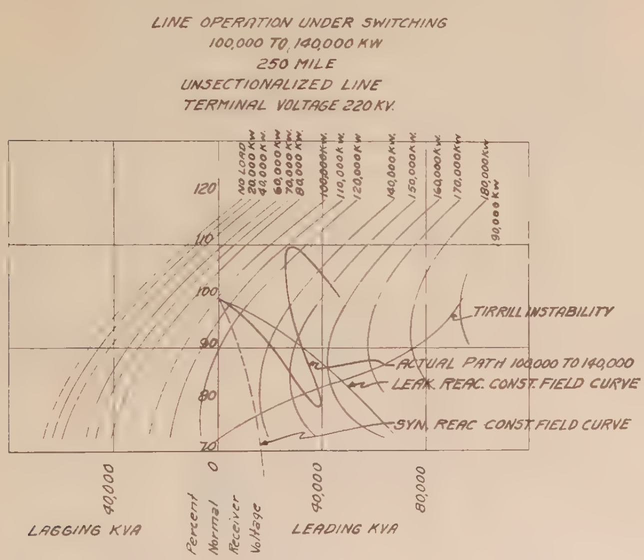

FIG. 1

should be qualified by the statement that various factors which radically affect the results have not been considered in their analyses.

PART I

R. D. Booth: Evans & Bergvall have analyzed the action of the Tirrill regulators on synchronous apparatus of the system for various steady-state voltages and found that instability occurred in the steady state at the points of tangency of the load and the field-current characteristics. However they apparently are applying this criterion to transient conditions. Mr. Moreland has, we believe, shown the fallacy of their method.

In particular we cannot agree that they have presented any substantiation for their general conclusions regarding the sectionalized line.

They have examined the load at which the regulators on the mid-point condensers become unstable in operation, and have assumed that this sets the maximum load limit for the system. Incidentally in this analysis they have assumed the receiver voltage to remain normal, and hence the only point of their curve of regulator instability which has physical significance is that corresponding to normal voltage. They have tested these conclusions by tests made with loads slowly applied through a motor-generator set. When a load is thrown on to the generator of the motor-generator set as in their tests, it does not become transferred to the system until the set falls back in phase. This occurs slowly enough so that their assumption of a succession of steady states is fairly close to being correct for this condition. But all of this leaves out of consideration what may happen in the system when a load increment is very suddenly added, as for example by the cutting out of circuit of a generating unit at the receiver end. In other words, they have examined one load limit for the system, but have drawn general conclusions which assume this to be the only limit which need be considered.

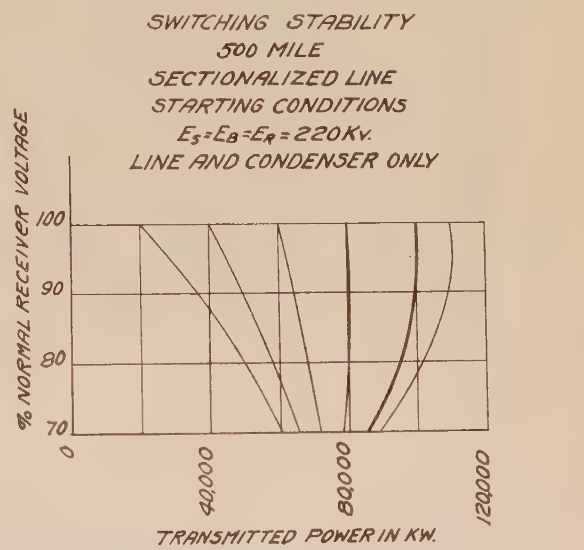

FIG. 2

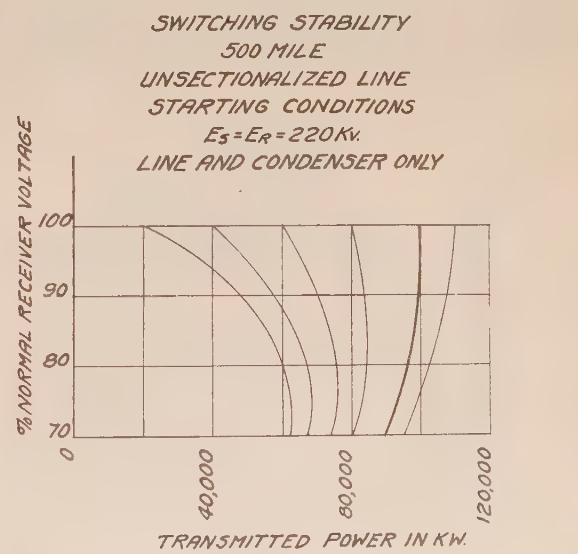

FIG. 3

In the early part of our analysis, we made for simplicity the assumption on which this paper is based, *i. e.*, neglecting the inertia of the condenser and the changes in the condenser fields. But we have examined on this bassis, in addition to regulator action in steady state, the effect of sudden switching. Even on this basis alone our conclusions as to the load limit of the sectionalized line would be very different from theirs.

We show in Fig. 2 and Fig. 3 the variation in receiver potential of the 500-mile line upon a sudden increase in load, Fig. 3 being for the unsectionalized line and Fig. 2 for the same line, with a mid-point condenser added. These curves were computed by

neglecting the inertia of the condenser as was done for the curves in the paper, but the changes of both terminal and receiver voltages in the sectionalized case were taken into account. The curves show the variation of receiver voltage upon suddenly increasing the load above that at normal voltage. The curves are here drawn for a load which is independent of the voltage, since this is the type of load considered in the Evans & Bergvall paper.

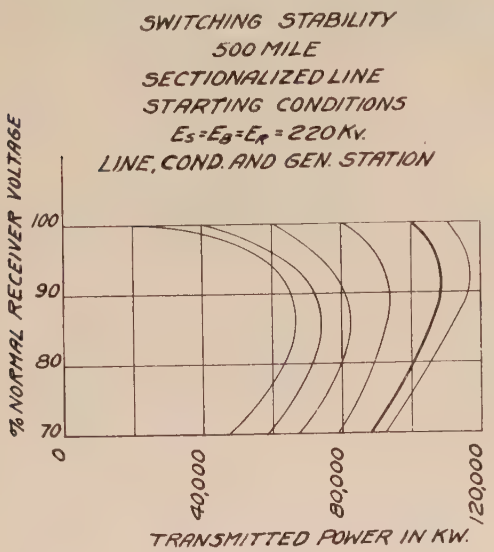

FIG. 4

It will be noted that the two curves of Fig. 2 and Fig. 3 above are not far different from one another. In each case they indicate that if the line were initially carrying 100,000 kw. a sudden increase in load of only 2 per cent, if applied before the regulators could act, would break the system apart. The curves are based, as are those of the paper under discussion, on the steady-state

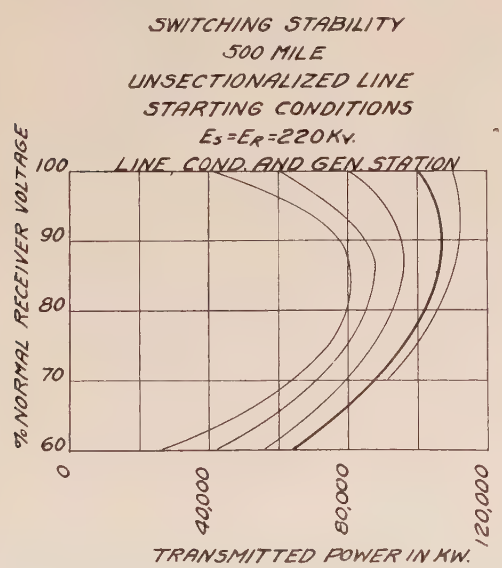

FIG. 5

characteristics of the condensers, that is, on their synchronous reactance, although, as noted, these do not strictly apply during such a transient condition.

In the statement of the methods followed in our analysis, you will note also that our studies include the coincident variation of receiver and mid-point potential for a sudden load increment, while the curves of the paper for the sectionalized line consider only the mid-point potential. It is the receiver-end potential that in this case actually sets the limit to load as far as switching is concerned, and for the sectionalized line it sets this limit far below the value found by the authors for difficulty with regulator action. Hence the premises of their paper, if applied to sudden load switching, indicate that adding a mid-point condenser with the mid-potential normally held at the same value as at the ends does not increase the capacity of the line appreciably for the type of load here considered. This is widely different from the conclusion of their paper that 40 per cent increase in capacity is obtained in this manner, and clearly indicates the need for

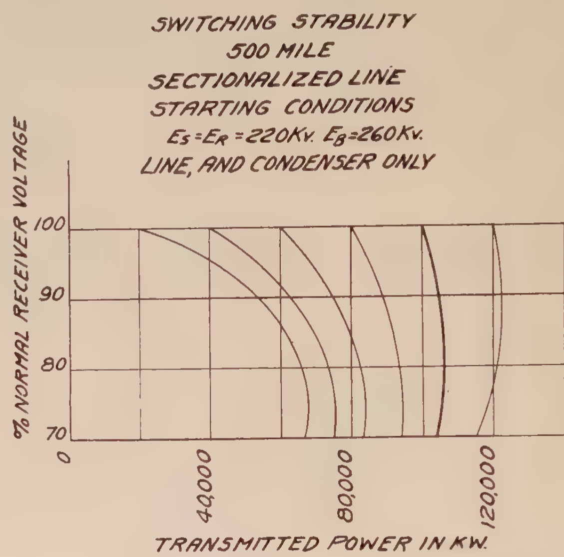

FIG. 6

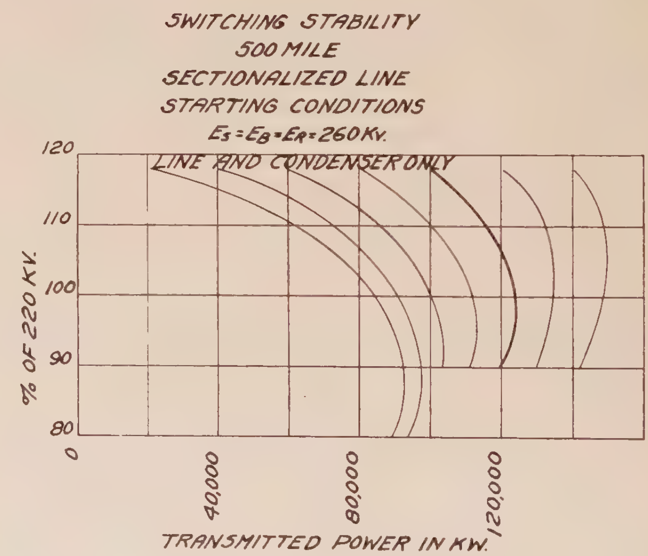

FIG. 7

complete study taking into account the factors here neglected. We have added, Fig. 4, a similar curve with the regulator at the mid point set to maintain normally 260 kv., and Fig. 5 for line voltage of 260 kv. throughout. The installed capacity of synchronous condensers is, of course, different for these cases. This indicates that there is some benefit by this voltage increase. The stability of the line for a load which varies with the voltage may be readily obtained by plotting the characteristics of the load on the diagrams here presented.

The stability of a transmission system is of course, affected by all rotary apparatus connected to it, and therefore we have

shown the effect of the synchronous apparatus in a large generating station connected at the receiver end of the transmission line.

It must be emphasized again, however, that the analysis of the paper and of the part of our work presented above, neglects certain factors which greatly modify the action during switching.

PART II

Note on Method of Computing Stability of the Two-Section Line

(*Kinetic Energy and Tirrell Transients Neglected*)

The method of computing stability curves for the line with a mid-point condenser will now be outlined. This is based on the assumption of no inertia in the condenser, so that the phase of the condenser is assumed to follow that of the terminal voltage instantly. We have also used the steady-state characteristics based upon synchronous impedance. This involves the assumption of neglecting the transients produced in the condenser field current by terminal voltage variation during switching. The characteristics based upon leakage reactance may be used

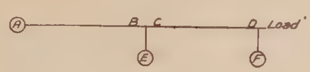

Fig. 8

instead, if desired, but this involves the assumption of neglecting the dying-out of field current transients. It is more conservative to use the synchronous reactance, so we have adhered to this assumption in our approximate analyses.

We have certain initial conditions on the system, and hence know the initial voltages, condenser fields, etc. We wish to examine the variation in voltage which will ensue if the load is suddenly increased from its initial value.

The method of analysis consists in general of finding a set of values which satisfies simultaneously the conditions at the mid point and the receiver end.

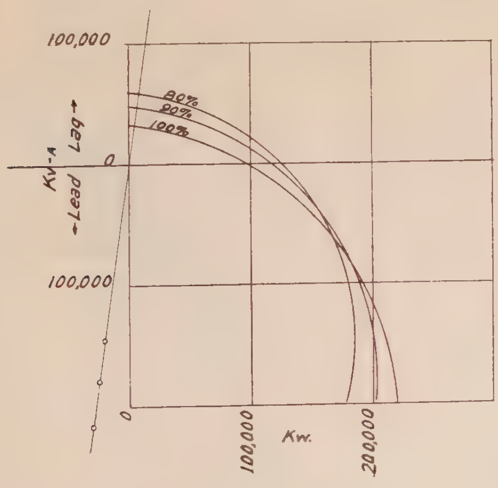

Fig. 9

The system we shall consider is as shown in Fig. 8. For the mid point we have the condition that the power at B drawn over the line must equal the input at C to the second section except for condenser losses. Also we have the fact that the difference in quadrature kv-a. at these two points must equal the kv-a. of the mid condenser. To satisfy these we will use the circle diagrams for the two sections of line, and the characteristic curves of the condensers at mid point.

Fig. 9 is the diagram for the first section based on a constant voltage at the generating station, and giving the relation between kw. and kv-a. at B for various values of mid-point voltage.

Fig. 10, drawn for the second section, is based on normal receiver voltage and similarly gives the relation between kw. and kv-a. at C for various values of mid-point voltage.

Fig. 11 gives the mid-point condenser characteristics, that is the variation of kv-a. output with terminal voltage for various values of condenser field current. The length (a) is the mid-condenser output for normal voltage at mid point and receiver,

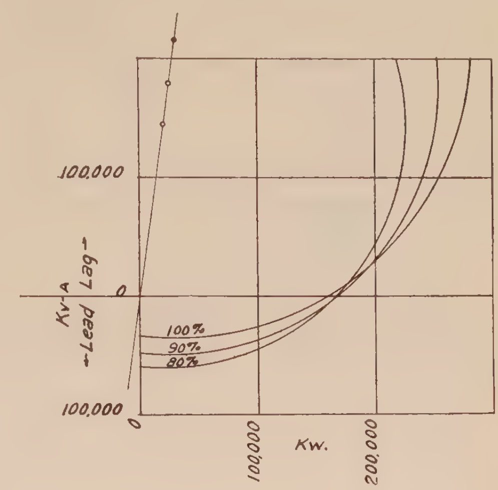

Fig. 10

and is found in the usual manner. The lengths (b), (c), (d) give the condenser output for this same field setting, and for various values of voltage at B.

Now superpose Fig. 10 on Fig. 9 as shown in Fig. 12 so that the scales coincide and pick off the values of kw. corresponding to a vertical distance between similarly labelled curves of the corresponding values (a), (b), (c), (d). Another way is to displace the curves vertically by the distances (a), (b), (c), etc.,

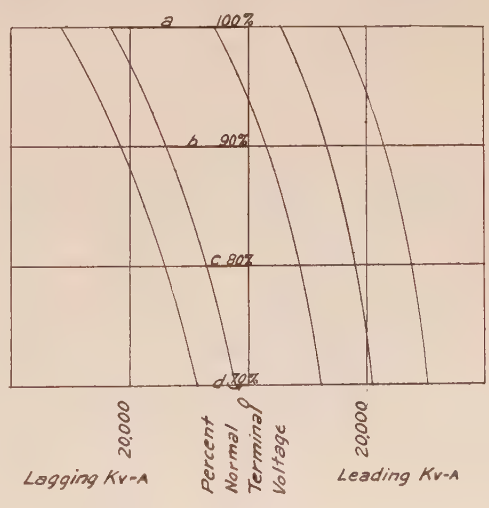

Fig. 11

in turn, as shown in Fig. 13 and read curve intersections. If the condenser output is lagging the curves will overlap. If it is desired to take into account condenser losses, the curves should simultaneously be displaced horizontally by the kw. of condenser losses corresponding to each successive value of mid-point voltage.

Now, convert the values of mid-point power to receiver end power, by means of a circle diagram. Plot the resulting values of mid-point voltage and receiver-end kw. as in Fig. 14 and label

the resulting curve 100 per cent E_r, corresponding to the normal receiver voltage which was assumed. It will be evident that points on this curve satisfy all conditions at the mid point for the assumed value of receiver voltage.

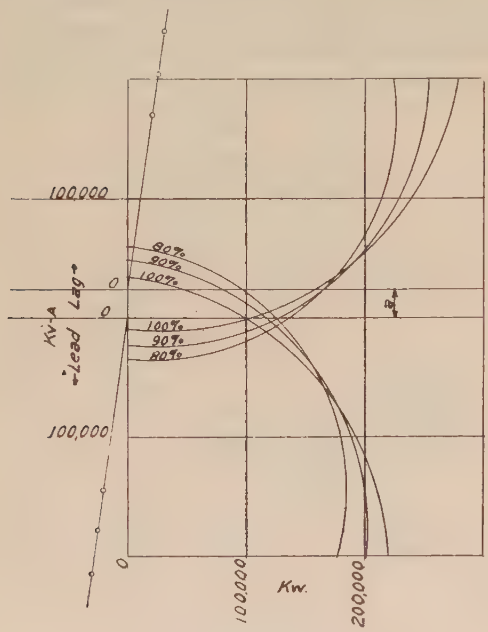

FIG. 12

Now, assume a new value of receiver voltage, for example 90 per cent of normal, use the circle diagram for the second section corresponding to this receiver voltage, and repeat this process. Plot the results as the curve 90 per cent E_r, in Fig. 14. Repeat for other values of E_r.

Turn now to conditions at the receiving end. We have here the conditions that the quadrature kv-a. of the line at D must equal the sum of the quadrature kv-a. of the condenser and the load. To satisfy these, use the circle diagram for the second section based on normal receiver voltage, Fig. 19, which shows the kw. and kv-a. over the line for various values of mid-point voltage. We make also a chart, Fig. 15, for the receiving end condenser, similar to Fig. 11, but based on a different capacity. Also we have the characteristic of the load, that is the variation in power factor of the load for different values of receiver end voltage. We can in addition take into account the characteristics of any generating station that may be connected to the receiver end of the line by adding them to the characteristics of the condenser station.

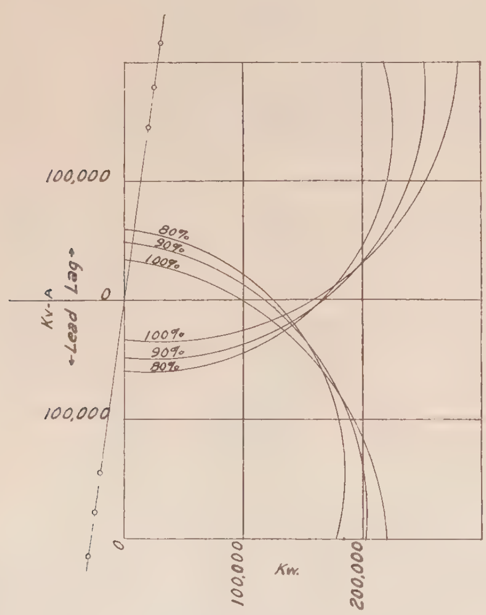

FIG. 13

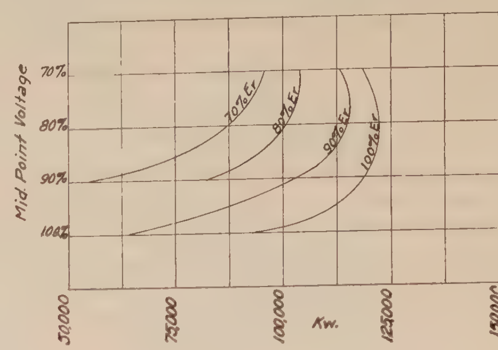

FIG. 14

FIG. 15

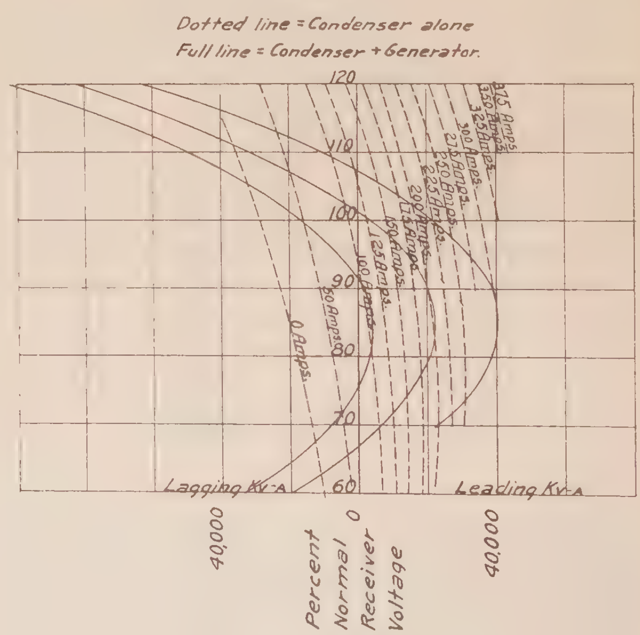

FIG. 16

An operating point for the receiver end for each mid-point voltage will be at a certain load at which the kv-a. of the line is

equal to the kv-a. of the condenser plus the load. These points are shown on the above Figs. 17 and 18. For any constant E_r chart, we will have but one condenser value to consider, this may be taken in connection with the load at that particular receiver voltage.

From the intersections on each of these charts we obtain a curve of operating points which would fulfill all the operating requirements of the receiving end for the particular receiver

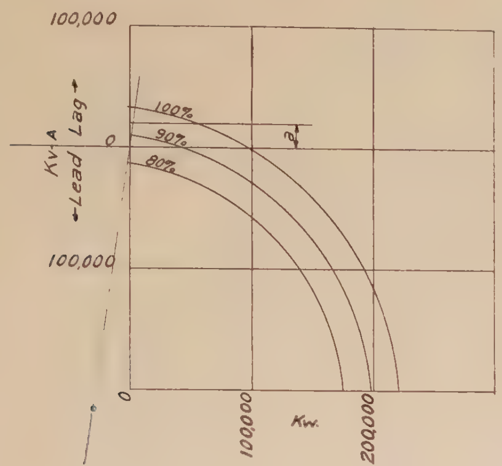

FIG. 17

voltage considered. We can then plot with voltage at the mid point against load at receiver end.

Calculations made with a number of these receiver charts for different receiver voltages will give a series of these curves for the different values of voltage at the receiver end, as shown in Fig. 19.

We now have two graphs plotted against identical functions, one of which shows the operating characteristics of the first

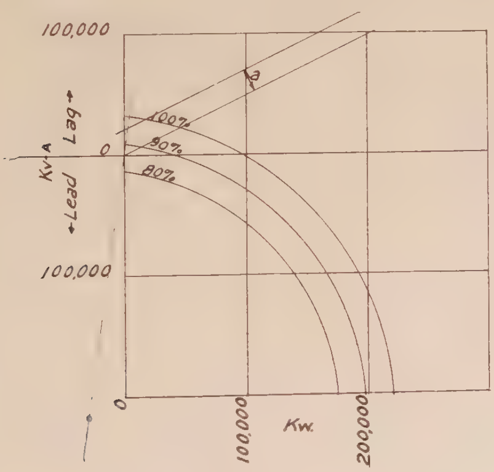

FIG. 18

section, and the other the characteristics of the second section; therefore by superimposing these as in Fig. 20, we can find the conditions which satisfy both sections. The intersections of the curves correspondingly labelled give values of receiving-end voltage and receiver-end power which satisfy all the requirements of the system. These points hence are operating points for the particular set of initial conditions considered. A group of these curves for various starting conditions shows the complete behavior of the line under sudden switching conditions with the single limitation that we have neglected inertia and condenser field changes in the computations. (Fig. 21.)

Upon this set of stability curves we can readily show the action of the line when loads of various resistance are applied. In Fig. 21 we have shown a set of stability curves with load lines representing fixed load of 85,000 kw. and another of fixed resistance of ohms.

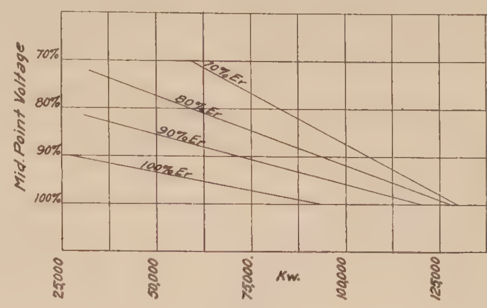

FIG. 19

With a line operating at 80,000 kw. and switching upon it a load of such character as to make the total equal to a resistance load as shown by line b we should have fallen immediately to point p and then as the regulator operated increase along line b to the operating point Q.

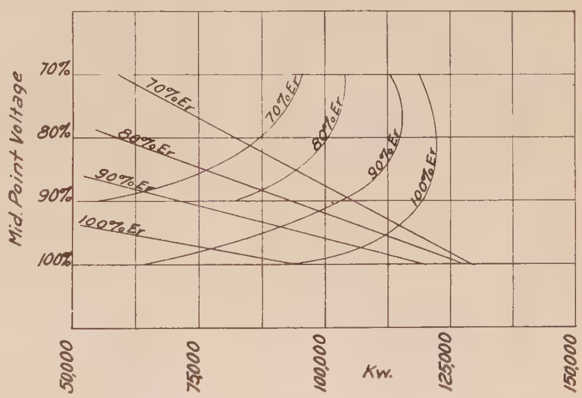

FIG. 20

It will be readily apparent that the above method can be extended to cover the case when load is drawn from or supplied to the mid point of the system. This is done by combining the station or load characteristics with those of the condenser at that

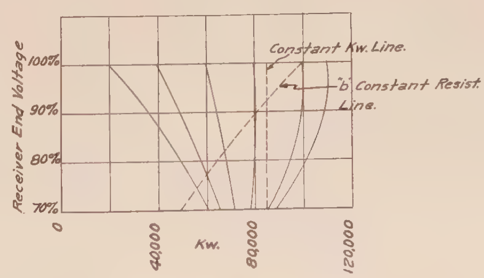

FIG. 21

point. Thus we have a method of treating a long line supplied with some power at a point along the line.

This proceedure undoubtedly appears laborious. It is really not, however, when the curves for lines and machines are once made available. Two computers can readily determine a complete sheet of stability curves in a day.

V. Bush: The criticism that has been made of Messrs. Evans and Bergvall's paper applies to the paper by Fortescue and Wagner. This paper discusses at some length the effect of kinetic energy in rotating masses, but so far as results from computations are concerned, the conclusions are based only on steady-state conditions and neglect the stored energy in rotating masses. Yet definite conclusions are again drawn in regard should not be drawn until the factors here neglected are taken into consideration in the computations. We have not been willing in our work to accept conclusions obtained by neglecting condenser overswing, etc. Hence we have analyzed the behavior of a line during switching taking into account the kinetic energy of rotating masses, the transients produced in condenser fields, and the action of regulator and exciter during the transient

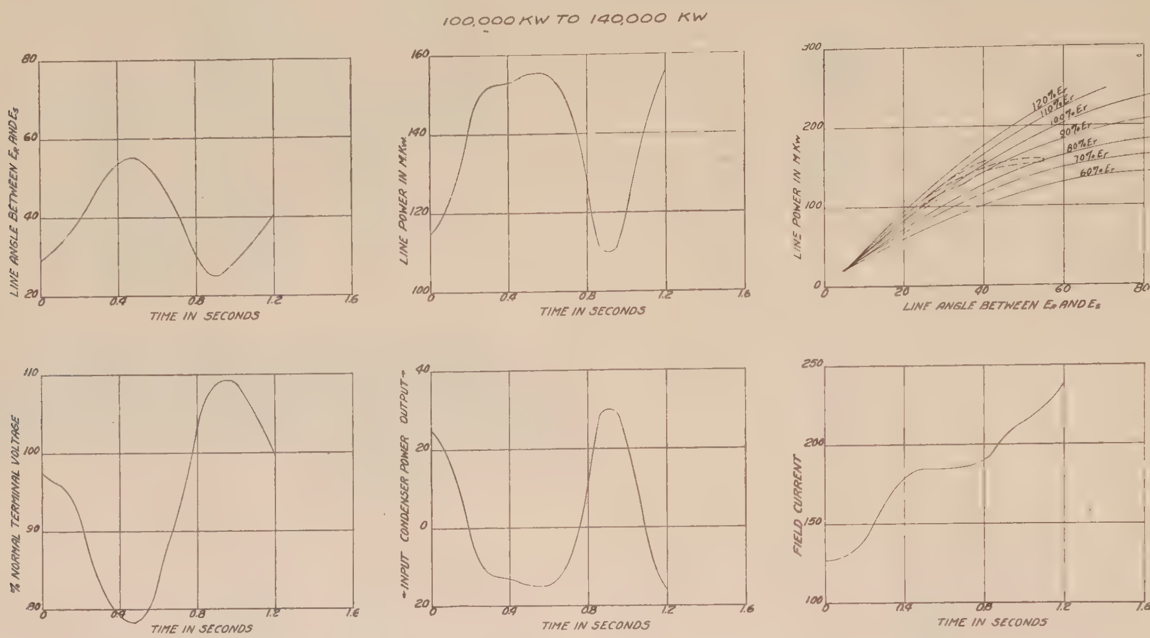

Fig. 22

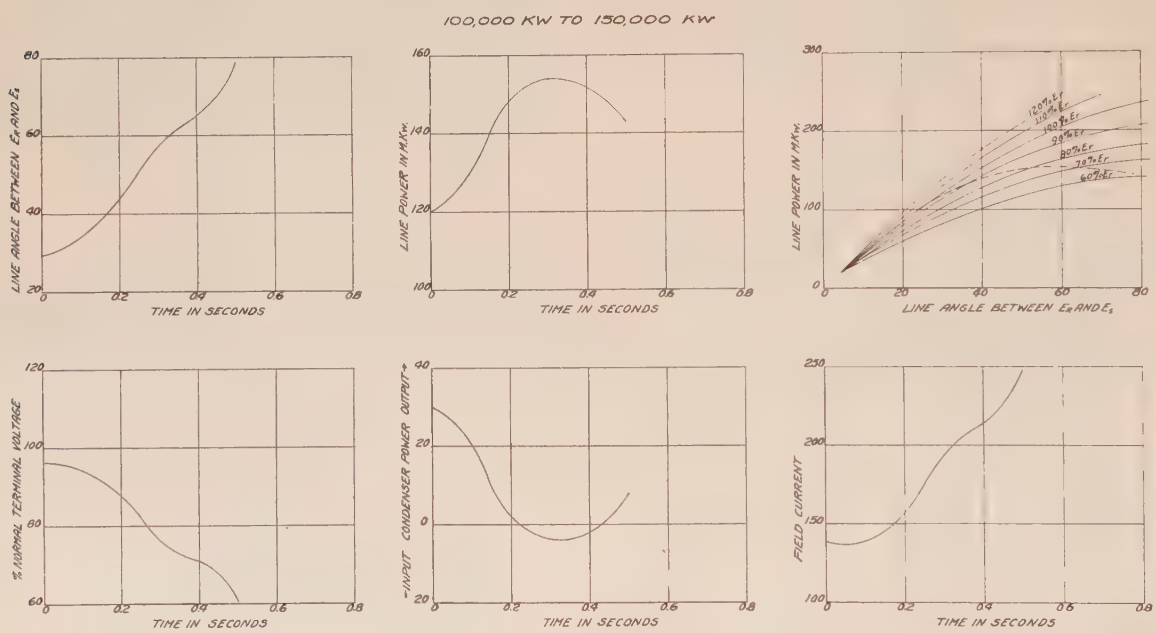

Fig. 23

to the increase in capacity of the line expected to result from adding a mid-point condenser. There is a qualitative discussion of the effect of some of the neglected factors and an arbitrary allowance of 25 per cent is made to take care of these, but this cannot be regarded as more than a guess. The authors evidently recognized that the factors neglected may be important, but they attempt no computations in which they are involved. Yet they proceed to draw general conclusions. General conclusions period. We have completed this analysis for a 250-mile single-section line and now have in process the analysis for a 500-mile double-section line. The analysis of the 250-mile line was made as it forms the first step in the analysis of a two-section line. In Fig. 22 is shown the effect produced on a 250-mile line by suddenly increasing the load from 100,000 to 140,000 kw., the load in this case being assumed to have unity power factor. The variation in terminal voltage, phase angles, condenser field cur-

rent and power from the condenser are shown. The field-current variation is controlled both by the terminal voltage variation and the effect of the regulator and exciter. In this case the voltage was restored and the system did not pull out of step. In Fig. 23 the load was suddenly increased from 100,000 to 150,000 kw. and the system broke apart. Similarly in Fig. 24 the load charge was from 80,000 to 13,000 kw. and the system held together; while in Fig. 25 the charge was from 80,000 to

In Fig. 26 are shown the stability curves of this same line neglecting the inertia of the condensers and changes in condenser field current during switching. It will be noted that they predict about the same load-switching limit as obtained by the complete analysis. This is, however, a coincidence. It happens that in this case the overswing of the condensers and the condenser field variation produced by voltage change and by the regulator, just about offset each other in effect. There is no

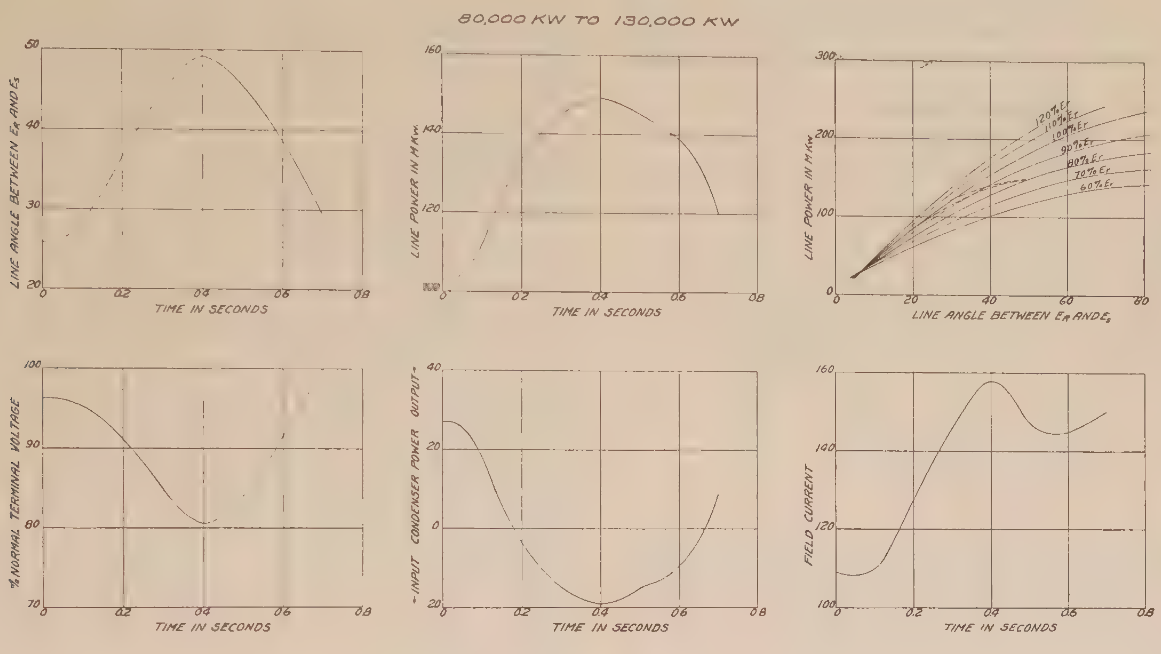

FIG. 24

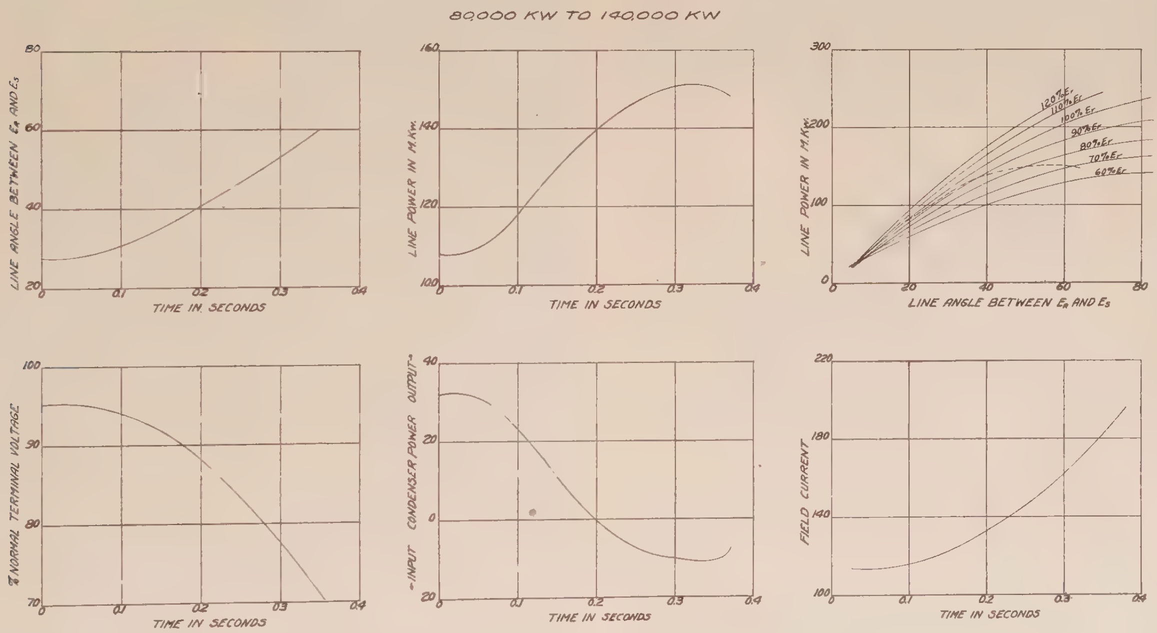

FIG. 25

140,000 kw. and the system broke apart. In each of these cases the amount of load in kilowatt was assumed to be independent of the voltage, since this is the type of load most readily considered in computation. Loads of a different character may be treated by the same analysis. The method of computing these curves and of taking into account the factors neglected in the papers presented here today, is too complicated to be explained at this time, but will be given in a subsequent paper.

basis, however, for any conclusion that this will happen generally; in fact, there is no such coincidence in certain other cases we have examined. We have presented here the curves applying to the line and condensers only, as this is the part of the system considered as a unit in these papers. The stability of this unit will, of course, be affected by all rotary apparatus connected. Mr. Booth, in his discussion showed the effect of a generating station as determined in that approximate analysis and shown in Fig. 7.

H. Goodwin, Jr.: Under the caption "Growth of High-Voltage Networks Introduces Control Problems" the *Electrical World* on September 8, 1923, outlined very ably some problems that are confronting those interested in such development and closed with the sentence: "Some genius has an opportunity to obtain a better solution to the general problems on such systems."

After outlining a comparatively simple network the editor asked these questions: How can the voltage regulation at each substation be controlled? How can the load dvision between generating stations be controlled? What are the limits of stable operation of the system if certain short circuits occur? Later the

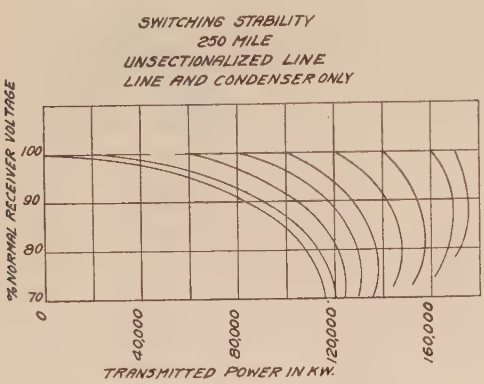

FIG. 26

present devices and methods are referred to as unsatisfactory for "the new type of system where an immense amount of energy is to be handled and reliability of service is paramount."

In the October 20, 1923 issue of the same paper there appeared a letter referring to the editorial and claiming that most of the points had already been answered.

But I and many others cannot agree with the correspondent and welcome most heartily the papers presented here today and congratulate their authors on the opportunity they have had to make the investigations and further on the simple terms to which they have reduced the problem in presentation.

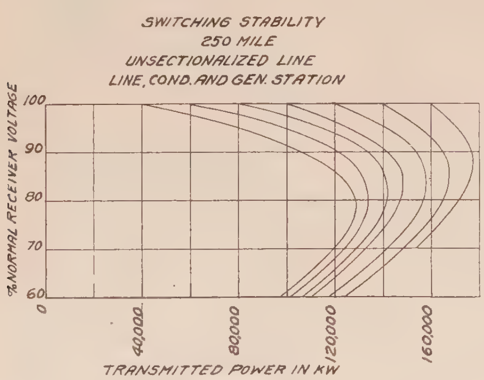

FIG. 27

Mr. Thomas' paper is a most excellent introduction to the subject (but not limited to introducing) and I should like to go into it and accentuate its many good points. But I shall have to pass on with recommending it for the study which only will give a full appreciation of its comprehensiveness. Issue might be taken with his suggestion of a 400,000-kw. substation. It would, in general, be better to split it in two or three. His detail proposal of generating and substation connections at first seems out of place, but on more careful investigation it is evident that a close relation exists between the general problem and these detail connections. The exact set-up has a considerable bearing on the operation of such a system as he is considering.

It is most interesting to compare the integral operation he gives, for his system under short-circuit conditions with that proposed for a superpower system in a report of considerable authority on that subject. The latter says: "If a short circuit occurs the system will be automatically separated at selected points into several systems that are complete in themselves, in order to limit the energy interrupted to amounts that can readily be handled."

The other papers deal with the circle diagram and advocate its use. May I suggest two other things almost as potent as the circle diagram for elucidating the details of action of a transmission line: 1st.: Following Dr. Kennelly in the use of polar coordinates for vectors wherever possible instead of the rectilinear form "$a + j\,b$." 2nd.: The use of "Qualitative Analysis of Transmission Lines" as a means of forming a mental picture on which to hang and by which to understand the detail mathematics. Mr. Thomas's paper is very good in the picture it gives of the system in addition to its mathematics.

On the first page of Messrs. Evans & Bergvall's paper, reference is made to the method of calculating circle diagrams previously given by Messrs. Evans & Sels in the *Electrical Journal.* This says in one place:[1] "When such a diagram has been finished, the most desirable conditions of operation can be readily selected, and the rigid mathematical solution may be applied to the particular case with any further degree of accuracy that may be desired." Later:[1] "The loss formula may be put in the form of a circle and plotted in connection with the regular circle diagram. This seems desirable to do, as the losses *neglected* when using the general circuit constants are practically constant for different loads, so that the most economical point of operating the line can be determined from the diagram." (Italics by the speaker). Yet do we find any "rigid" check of any of the results taken from the circle diagrams? And some results are almost hair-splitting.

Perhaps the paper by Messrs. Fortescue and Wagner, giving a more vigorous proof is supposed to serve instead. But why then refer to the old articles? Also, Messrs. Fortescue and Wagner do not refer to the "Loss Circle." Can it not also be proved by rigid mathematics? These questions are not post mortems. The old articles by Messrs. Evans and Sels have been made a part of the present group by reference. The circle diagram has had a very checkered career in the past. If it is now to be used as the foundation for a great forward step in the art, as in these papers today, it must be cleared of all doubt and set forth in new clean clothes. Messrs. Fortescue and Wagner do this in part. How about the rest particularly the "Loss Circle"? Has anything been "neglected" in the use of the circle diagram in these papers?

There is apparently duplication between several of the papers. This may have the advantage of giving different points of view of the same subject. But on the whole it seems that it would have been preferable, since the authors are so closely associated, to have put all related matter together in the best form and devoted the remaining space to some phases that have not been covered, *e. g.*:

A fuller development of the problems involved with comparatively short ties of large capacity systems such as: Newark & Philadelphia; Baltimore & Washington; East Central & West Central Pennsylvania. These are of almost immediate importance.

(Messrs. Evans & Bergvall give a most encouraging point in this connection on page 15. It appears that a number of stations in parallel along a line will help to hold each other in step at times of short circuit.)

The design of synchronous condensers to meet the requirements found, instead of assuming present design as the limit of operating conditions.

In the discussion of a 750-mile line, Messrs. Evans & Sels paper there does not appear to be proof of the statement, "the receiver

1. *Electrical World*, Decembe. 1921, p. 530 and p. 533.

must operate at lagging power factors," etc. and this is apparently at variance with Messrs. Fortescue and Wagner, in regard to a 500-mile line requiring 15,000 kv-a. *leading* at the receiver. In the next paragraph the reasons for limiting to 250 miles are not at all clear.

In the same paper the notation used in the equations is not standard or defined. It is assumed that the special symbols indicate vectors and conjugate vectors.

We meet the suggestion that "the condenser capacity Q_R may be chosen as equal to $(- m\ E_R{}^2)$." On looking for the value of m in equation (26) we find it is imaginary. Referring to Pender's Handbook page 240 we read:

"A real quantity cannot be equal to an imaginary quantity."

But even if these differences can be adjusted more detail of references are necessary to clarify the process of deduction and prove its correctness. It is not clear that the balance of equation (26) will not have an angle in it in addition to the j.

"Infinite" condenser capacity is referred to in some places while "unlimited" is used in others. Infinity is a rather dangerous toy and if the discussion could be confined to "unlimited" some will follow the deductions with greater ease and assurance.

Mr. Shand draws inferences from my paper of last year "Qualitative Analysis of Transmission Lines" and then proceeds to find fault with them. At the time the paper was presented, two of the other authors of today's papers "by inference" developed things to discuss adversely that were not in the paper. The one inference to be drawn from that paper and the whole point is that an understanding of the fundamental physics and most simple mathematics of the transmission line and the "critical load" derived therefrom are of the greatest benefit in understanding the action of a line and such detail mathematics as have been presented today.

The paper of last year showed a simple method of determning the critical load of a line and the characteristic action of loads above and below this on present commercial lines. It was then shown, by example, that if the critical load was put on an extra long line in a certain way, there would be no reactive energy drawn from synchronous condensers even if they were placed along the line. The circle diagram was then used in adverse discussion. It is most interesting ot see its use here confirm the points made in last year's paper: In Mr. Shand's paper, read of operation at critical load, that the intermediate condensers "might be merely floating on the line without carrying reactive current." In Messrs. Fortescue and Wagner's paper, read the author's judgment that while with large amounts of synchronous-condenser capacity distributed on a 500-mile line, larger loads would be possible, the practical rated load would be the critical load. "The actual reactive power required at this load is zero at the midpoint and about 15,000 kv-a. leading at the receiver." In the discussion last year the circle diagram was used to prove that the most efficient operating conditions would be with reactive kv-a.

Your attention is also drawn to the many circle diagrams and the general intersection of the circles at the critical load and a slightly leading power factor which is to be expected from qualitative analysis.

Now these things are not said to continue or develop a controversy but to point out that in today's papers a difficult subject has been ably dealt with. The subject is so difficult and involved with so many practical considerations, that it is apparently impossible of general mathematical solution. The only means at hand is the working out of specific problems and generalizing from them. Generalizing is a difficult and dangerous thing without a guide. The best guide I know is qualitative Analysis, enabling one to relate the results of a specific problem to the fundamental physical conception and thereby be able better to judge the effect of change of any of the conditions or constants.

A. E. Silver: One point in Mr. Thomas' paper of particular interest is that of the avoidance of all switching on the 220-kv. side as shown in the circuit diagram, Fig. 5. This scheme is ingenuous and embodies many advantageous features. However, I believe it doubtful if there can be anticipated many actual situations, when analyzed on the basis of probable conditions, in which high-tension switching can be advantageously avoided. Any 220-kv. transmission development that may at present appear to offer some probability of materialising in this country, would, I fear, prove unsuited if laid out without at least providing for later high-tension switching.

Especially at the receiving end of such a system it may be expected that interconnection between large load centers will occur hand-in-hand with, and in some cases precede, the construction of long transmission circuits of this kind coming in from distant water powers or fuel fields. It also may be expected that circuits for such interconnection must be of capacity commensurate with that of the long 220-kv. transmission circuits, otherwise full advantage cannot be taken of such factors as load diversity, reserve capacity in existing plants and load equalization over generally parallel circuits. Should several long 220-kv. lines emanate from one center of generation it is probable that, in the beginning at least, they would diverge at the receiving end so that one or perhaps a pair of circuits would deliver at each of several separated major load centers. The reserve against outage of any such 220-kv. circuit would in considerable part be provided over the interconnecting circuits between these receiving stations. Such interchange through the medium of the network on the low-voltage side of the 220-kv. transformers would, in general, appear inadequate and uneconomical because of the relatively large increase required in the transformers and lower voltage line capacity.

In other words, regardless of how simple the beginning may be, I believe the prevailing situations in laying out such a 220-kv. system will require looking ahead to a process of extension that will continue until it has developed and merged into a 220-kv. network embracing several or many major load centers and extending over a wide power consuming area. It would seem impracticable to develop such a network simply and economically and with the needed flexibility if based on other than 220-kv. switching.

At the generating end of such a group of long 220-kv. transmission circuits it occasionally may occur that the supply will be derived from a single large development so located relative to other power developments as to preclude the practicability of tying together at 220-kv. It is believed, however, that the more frequent condition will be the supplying of such a group of circuits from several moderately large plants separated by appreciable distances, as for example, a series of developments along a river. Usually, therefore, it is believed that 220-kv. switching at the generating end will be better suited for flexibility and load equalization.

As Mr. Thomas points out one definite disadvantage of the scheme of eliminating 220-kv. switching which places the transformers as an integral part of the line is the fact that the overload capacity of transmission circuits is entirely dissimilar to that of transformers. The overload characteristic of a transformer is similar to that of a generator, that is, a definite limit relatively close to normal-capacity rating beyond which the apparatus cannot be loaded without damage from heating. On the other hand, the transmission circuit has no such limitation as concerns its own safety, its practical load limit being set by voltage-regulating equipment. Economical design may permit a load, on shorter lengths of line, as great even as several hundred per cent of the load normally carried on a circuit.

It is thus evident that for utilizing the overload capacity of any of the circuits during times of maintenance or emergency, the needed flexibility can most readily be obtained by paralleling and switching on the 220-kv. side.

A system designed for 220-kv. paralleling and switching, I believe to be capable of greater simplicity than a similar system laid out for equivalent load equalization and emergency transfer of power entirely through the network on the low-tension side of the 220-kv. transformers.

It must be recognized, of course, that adoption of 220-kv. bussing and switching for an interconnected network places the problems of circuit and apparatus arrangement, design and performance in a field of magnitude well advanced over that of the more or less conventional practise of today for lower voltages. It means that persistent attention must be given to developing and perfecting simple and dependable circuit and switching arrangements and apparatus including selective relaying and switch operation. Of particular importance is the problem of suitably dealing with short-circuit conditions. Also there will be required simple and effective devices for 220-kv. synchronizing and metering and for performing any other functions which would logically be required in the major bus of a station where the lower voltage switching facilities have been minimized. There seems no good reason to doubt that by persistent effort these devices and methods will be made available as needed.

It is, of course, not the intent of Mr. Thomas' paper to cover the situation of 220-kv. networks which I have tried to describe but rather the case of a single large generating center directly connected by high-tension lines to a single large receiving station. I am sure we would all appreciate an extension of his studies to include this companion problem of an interconnected network of large generating and receiving centers.

Mr. H. R. Summerhayes: The papers show that the transmission engineer is in the position of a navigator approaching an unfamiliar coast who pauses to take soundings, consult his charts and get bearings on a lighthouse or some established guide to navigation.

This subject of long distance transmission is of especial importance now because of the financial and economic pressure. A 500-mile line under certain conditions of cost of water power and price of coal, must transmit in the neighborhood of 100,000 kw. to justify the construction of the line from a financial and economic standpoint.

It would be easy probably to transmit 50,000 kw. over a 500-mile line, but when it comes to 100,000 kw. we are approaching the limit, as far as practical operation is concerned. A 250-mi. line is of the order of fifty or sixty per cent reactance when you are considering one hundred thousand kw. A five hundred million is over a hundred per cent reactance and it becomes a rather thin tie between generating stations of that size and larger. I think that several of the speakers discussing the papers have called attention to the fact that the transient condition should be considered and some engineers whose work I am familiar with have given special attention to these points, that is, to the sudden addition of load and what happens on the line when an increment of load is suddenly added.

To me the most significant part of these studied is the effect of the high reactance in the reduction of voltage.

Now, speaking of the charts of the navigator, the engineers have made some very creditable and thorough studies and we have been introduced to curves and whole families of curves, not simple ones but a lot of them so that one begins to think we are not only approaching the limits of transmission, but the limits of understanding the human mind. We meet so many of these curves and try to understand them that it becomes difficult.

However, this voltage question is large, and one can't put the whole subject in a nutshell, but it does seem to me that one conception of it is this: that you have to have voltage enough to transmit the power. If you suddenly increase the load so that the voltage momentarily goes down and there isn't voltage enough left to transmit the increased power, then before your voltage regulator can get busy your station will fall out of synchronism and the determination of that point of lost stability is the aim of a great deal of this work.

Edith Clarke: Messrs. Evans and Sels have explained the calculation of transmission lines by means of circle diagrams in a manner which is clear and easy to follow. I read their treatment of the subject in the *Electrical Journal* and have employed it in transmission line calculations. It is an accurate and rapid method. A complete circle diagram can be made in less than an hour and all information in regard to the transmission line is then available.

I have been accustomed however, to presenting the results of transmission line calculations in a different manner, and as this method shows clearly the variation of the receiver voltage as the load is increased or decreased, the generator voltage remaining constant, I have prepared a chart to illustrate it. (Fig. 28).

This chart illustrates a method of plotting results of calculation. The calculations themselves can be made by any method whatever. In this particular case, the calculations were made on the transmission line calculator described in the *General Electric Review* of June 1923. Such curves can be run off in a few minutes by using the calculator. They could be made as well from values taken from the circle diagram. The circle diagram could also be made from these curves.

Fig. 28 shows two families of curves, one for a 100-mile line, the operating characteristics of which are familiar to you, and the other for a 500-mile line which is the subject under discussion.

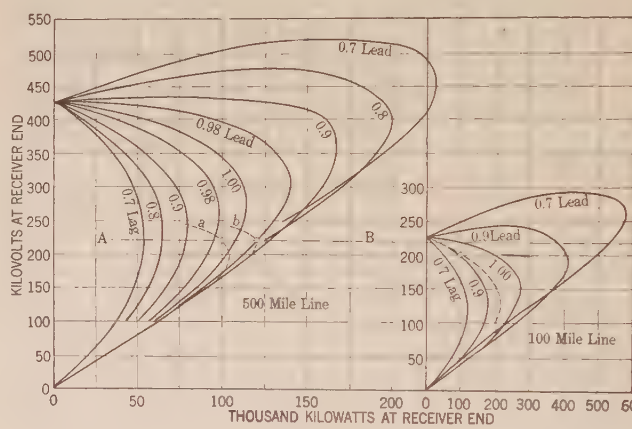

Fig. 28

You will notice in these curves kilowatts at receiver end against kilovolts at receiver end, generator voltage remaining constant for various power factors at receiver end. For each power factor at the receiver end there will be a different curve. The same conductor is used for both families of curves, the same frequency (60 cycles) and the same generator voltage (220 kv.). They have the same general shape. They are like the regulation curves of a shunt generator. With no load at the receiver end on the 100-mile line the voltage of the receiver is 225 kv., while on the 500-mile line it is 425 kv. due to the large charging current.

Let us look at the 100-mile line first. It is customary to operate such a line with the receiver voltage lower than the generator voltage and with a power factor of unity or less. If we follow the unity power factor curve, starting off with no load at the receiver and adding power, the receiver voltage continues to drop until we come to the maximum power for this power factor. This point is far below the usual operating voltage. It will be noted that as the power factor increases towards leading, the voltage at which the maximum power occurs becomes higher. Maximum power for a given line insulation is obtained by having the voltage at both ends the same, *i. e.*, with kilovolts at receiver equal to kilovolts at the generator. For the 100-mile line with kilovolts at the receiver equal to 220 kv., for maximum power we would have a power factor of about 0.7 leading and could deliver over 500,000 kw. Notice however, that we are now operating

on the underside of the curve for 0.7 power factor leading and the case is comparable with the 500-mile line.

Let us pass to the 500-mile line. As we go out along the line A, B, Fig. 28, (220 kv. receiver equals 220 kv. generator), a more leading power factor shows an increase in kilowatts until we come to the limit of the line at this voltage. For the line chosen the limit is about 130,000 kw. and the power factor is 0.9 leading while 0.8 power factor leading gives less power and 0.7 less still. This same thing has been shown on the circle diagram. With the receiver voltage equal to the generator voltage, for all constant receiver power factors we are below the maximum power points. Therefore, the 500-mile line would be unstable for a shaft load of constant power factor. Fortunately however, an induction or synchronous load does not have a constant power factor but a power factor which becomes more leading as the voltage drops and more lagging as the voltage rises. The constant power factor curves, therefore, are not the curves of receiver power against receiver voltage for induction and synchronous loads. You will notice two dotted curves. These are for induction motor loads in parallel with synchronous condensers with constant excitation on the condensers. The circles indicate the points of normal voltage operation. In Curve a we are delivering 100,000 kw. with normal voltage of 220 kv. An increase in load is accompanied by a drop in voltage and an improvement in power factor. Beyond a certain point, however, a drop of voltage means a more leading power factor but no more load. In Curve b we are delivering 120,000 kw. with normal voltage of 220 kv. We cannot get any more power with a drop of voltage although we get a more leading power factor. There is no margin. Now look at the dotted curve in the 100-mile line graph. We have the same load and the same condenser as in the dotted Curve a on the 500-mile line graph. We have also constant synchronous condenser excitation. A drop of voltage is accompanied by a more leading power factor and also more load, so that we can pass from 100,000 kw. to 200,000 kw. and beyond before we reach the maximum power point. The 100-mile line is stable for the load chosen, but the load is far from the maximum power the line will deliver. The 500-mile line looks dangerous for we are very near the maximum power of the line at 220 kv.

We can increase the maximum power of the 500-mile line by raising the voltage, by reducing resistance or reactance or by going to a lower frequency. A higher voltage would increase the maximum power as the square of the voltage. Decreasing the resistance when it is small in comparison with the reactance makes but little difference in the maximum power. Decreasing the reactance in the manner proposed by Mr. Percy Thomas, in a paper before the Institute in 1910, by employing split conductors, would increase the maximum power by 50 or 60 per cent. Decreasing the frequency to 25 cycles would make the 500-mile line equivalent to a 60-cycle line whose length is 500 X 25/60 = 208 miles, but whose resistance is inversely as the frequency or 60/25 as great. With 25 cycles, more than 150,000 kw. can be delivered over a 500-mile line with stability assuming constant generator terminal voltage.

The use of a synchronous condenser in the middle of the 500-mile line as suggested by the authors, will increase the maximum power that can be delivered over the line. Assuming 60,000 kv-a. in condensers at the mid point and constant voltages of 220 kv. at the generator and receiver ends but constant field on the condenser at the mid point, I find we could deliver approximately 150,000 kw. which agrees with the 152,000 kw. mentioned in Messrs. Evans and Bergvall's paper. In arriving at the 107,000 kw. mentioned in their paper for the rating of the line without condenser in the middle, constant field was assumed on the receiving end condensers but not constant field on the generators as voltage was assumed constant at the terminals of the step-up transformers. In arriving at the 150,000-kw. rating of the line with condenser at the mid point, constant field was assumed only on the condensers at the mid point. Both of these ratings would be very materially reduced if constant field were assumed at all points. Mr. Doherty discusses this phase at some length and gives some figures as to what this maximum power rating may become.

The curves in Fig. 29 are plotted as the others were, with kw. at the receiver against kv. at the receiver, (or per cent normal receiver voltage) and with constant generator voltage. I have assumed the condition shown on the graph. The upper set of curves is for the 500-mile line without condensers in the middle. The solid curves are for a constant generator voltage of 220 kv. at the terminals of the step-up transformer. A 70,000-kv-a. condenser was assumed and a load power factor of unity constant with voltage. The losses in the transformers and condensers

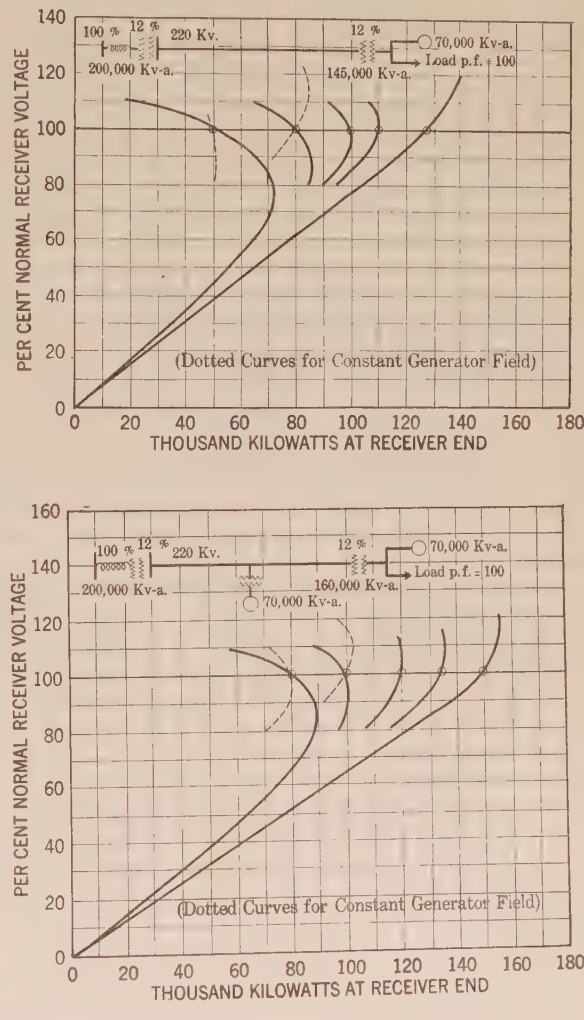

Fig. 29

have been neglected. The condenser field was adjusted to give the proper power factor for getting the assumed load over the line at normal receiver voltage of 220 kv. The field was then held constant on the condenser and the graph of kw. against kv. plotted. The circles indicate the points of normal voltage operation. When delivering 100,000 kw. at normal voltage we are above the maximum power point and when delivering 110,000 kw. we are below it. The maximum power possible over this line with constant generator voltage equal to 220 kv. and with the condenser capacity and load power factor assumed, is therefore, about 107,000 kw. as has been stated. The dotted curves are for constant field on the generator. The maximum power in this case is approximately 70,000 kw.

The lower graph of Fig. 29 is for the 500-mile line with con-

denser at the mid point. The solid curves are for a constant generator voltage of 220 kv. at the terminals of the step-up transformer. The receiver voltage has been allowed to vary with the addition of load as well as the mid-point voltage. Messrs. Evans and Bergvall held the receiver voltage constant and allowed the voltage at the mid point of the line only to vary with a change in load. With a 70,000-kv-a. condenser at the receiver and a 70,000-kv-a. condenser at the mid point and constant excitation on these condensers, the lower graph of Fig. 29 shows how the receiver voltage varies with the load. The circles indicate the points of normal voltage operation. When delivering 100,000 kw. at normal voltage we are on the upper side of the curve, but if 2000 kw. were added suddenly, before the regulator could increase the field on the condenser the voltage would fall, and if the load were a shaft load, it would fade away. When delivering 120,000 kw. at normal voltage we are already on the underside of the curve and for a shaft load we are unstable at this point. The maximum power, therefore, with the condenser capacity assumed and constant generator terminal voltage is less than 120,000 kw., probably about 118,000 kw. The dotted curves are for constant field on the generator. The maximum power in this case, is approximately 90,000 kw. It is possible by increasing the amount of condenser capacity to get more power over this line with a condenser in the middle. However, calculations made with a 150,000-kv-a. condenser of the usual type at the end and at the middle of the line, show that it is not possible to get 150,000 kw. over the line with stability assuming constant generator terminal voltage. If the generator field instead of the generator terminal voltage is assumed constant, the case would be worse. An increase in the amount of power with stability can be obtained if a special highly saturated synchronous condenser is used at the middle of the line.

If it is necessary to transmit 150,000 kw. per circuit 500 miles, I feel sure that it will be done, if not with the equipment at present commercially available, then by means of specially designed apparatus.

R. E. Doherty: While I would not detract one iota from the many points of real value in these papers, I nevertheless believe that a wrong impression may possibly be obtained from them as to the maximum power limit of such long lines, and I therefore wish to submit for your consideration the maximum limits which, in the present estate of engineering knowledge and experience, I consider to be justified.

After a careful and extended investigation, and considering the present experience and the extent to which the proposed colossal project of a 500-mile line extends beyond the bounds of experience, my conclusion is that the estimates of the maximum power given in these papers are too high. Take the case of a 500-mile straightaway transmission; where the authors proposed about 110,000 kw., we calculate about 70,000 kw. in the case of the sectionalized line with a 70,000-kv-a. condenser in the middle. Where they propose 150,000 kw. our estimate is 90,000 kw. These figures represent the maximum power which can be transmitted over the line at 220 kv. with the synchronous apparatus assumed. All assumptions are the same as those stated by the authors, excepting the generators. I have assumed a 90,000-kv-a. generator with the usual degree of saturation, and with 60 per cent synchronous reactance: which is equivalent, so far as the above results are concerned, to a 90,000-kv-a. generator with 45 per cent synchronous reactance, in which saturation is negligible. The usual value of synchronous reactance is about 100 per cent. The authors assume, in the calculations, that it is zero, when they assume constant voltage, *i. e.* $\frac{d\,E}{d\,P} = 0$.

Do not misunderstand. This difference in maximum power does not come from differences in premises, methods of calculation, or character of the synchronous apparatus considered. It is altogether a question of assumptions. Starting with the authors' assumptions, and with the same theory, long since generally accepted, we naturally arrive at the same conclusions; but the difference in assumptions is just the difference between 110,000 kw. and 70,000 kw. in the case of straightaway transmission, and between 150,000 kw. and 90,000 kw. in the case of a sectionalized line with a condenser at the mid-point.

The difference in assumptions is this: in the case of 500-mile straightaway, the authors assume a constant voltage at the generator terminals, or perhaps at the high side of the transformer; that is, they neglect the fact that the synchronous generators impose limitations upon maximum power in the same manner, and to a comparable extent, as the synchronous apparatus at the receiving end. That is, the difference in this case is altogether that they have neglected the effect of the generators, and we have included it.

In the sectionalized line with the condenser at the mid-pont, Messrs. Evans and Bergvall have not only neglected the limitations due to the synchronous generators, as all of the authors have done in the straightaway line, but have also even neglected the limitations imposed by the synchronous condenser at the receiving end—which limitations they had considered of sufficinent importance to include in calculating the straightaway transmission. In other words, in the sectionalized 500-mile line, the only limitation considered, outside of the line itself, is that imposed by the condenser at the middle of the line. That is, the difference between our conclusions regarding the sectionalized line is that the authors have neglected the limitations of the apparatus both at the sending, and at the receiving, end, and we have not.

Therefore, in comparing these conclusions, I wish to make it clear that the difference in results arises, not from any difference of opinion as to the fundamental theory of the transmission line, of the apparatus involved, or from essential difference of method, but only from a difference of opinion as to the importance of taking into account in the calculations the limitations imposed by the certain groups of the apparatus involved.

What about these assumptions? Which of them is justified? I submit that the colossal magnitude and importance of the long-distance lines now under consideration, and also the extent to which, in this study, we are projecting beyond the limits of experience, both demand that we adhere to the following principle: That we must show the system to be *inherently* stable—that is to say, we must neither gamble that a voltage regulator will be able to insert a supporting prop under an otherwise falling system, nor *depend* for stability during load transients, upon possible, momentary, favorable conditions due to momentum and field transients. These may add up in the right direction, but engineers had better keep them up their sleeves, just as they have done in the past in most other apparatus applications, particularly in generating and transmission equipments. Moreover, it should not be forgotten that the values here discussed are the ultimate maxima of power that can be transmitted at normal voltage with the apparatus considered. These are factors which must be carefully accounted for in deciding what asumptions are justified, and what are not.

The point of view which I am here outlining is presented in a masterly way in the first few pages of Mr. Shand's paper—which pages I should commend to your very careful study. After discussing generator characteristics and voltage regulators, he says, "This theory of artificial stability, although perhaps not a practical possibility, is here outlined mainly for the purpose of preventing any misconception regarding the capabilities and limitations of the commercial vibrating regulator in connection with the present subject. Moreover, if the state of artificial stability were attainable it is very doubtful that it would be desirable to depend on this apparatus as the main link in maintaining the operation of the system. In deriving the limit of output for power system it may be considered that the condensers are operating under a definite value of excitation for each value of load, this value being adjusted by the regulator as the load

conditions change." Then, somewhat as a shock, he follows up with this statement: "In the following discussion the effect of the inherent voltage regulation of the main generators has been neglected. This is justified on the grounds that the error is slight while the labor involved would increase greatly." What do Evans and Bergvall say? "In this investigation the voltages at both ends of the line were assumed to be constant. Actually the voltage regulators at the generator and receiver synchronous condenser cannot change the voltage instantaneously and some variation in voltage will occur. This does not appreciably affect the pull-out point as can be seen from the tests."

Now I think it is perfectly clear from the foregoing that there is complete agreement in fundamental theory, and in our conceptions of the general character of the behavior of all apparatus involved. But when we come to the point of making actual calculations—then, and not until then, we reach the point of disagreement. It is merely a difference of opinion as to whether the limiting effects of synchronous apparatus, which we both acknowledge, are significant or not; I am certain that they are. And inasmuch as we do agree in theory, it is only necessary for the authors to make the calculation including these effects, even if it is greater labor, and they will undoubtedly find substantially the same results. As a matter of fact, Mr. Shand has already calculated for a 300-mile line, the effect of the limited condensers at the receiver—still neglecting, however, the limitations of the generator. Why not do it for a 500-mile line, take the final step to make a complete job of it, and include the limitations of the generator. That would be more convincing than to assume that the factory test settled it. The difference is on the wrong side to let the test settle it.

I hope I have made it clear to you where the difference in results arises. The doctors do not disagree regarding diagnosis, nor as to the treatment, but merely regarding the *extent* of the treatment. And I trust that further study and calculation will bring agreement there.

T. A. Worcester: As has been brought out in some of the discussion this afternoon, the practical load limit of a 500-mile, 60-cycle line is not more than 100,000 kw., probably is in the neighborhood of 80,000 kw. If this is the case, it is well that we check up to see whether such a line would be economically practicable. The cost per kw. year of a 60-cycle transmission system to deliver 80,000 kw. per circuit is about \$29. This figure includes the transmission line, step-up and step-down transformers and synchronous condensers, and to it must be added the cost of generation of power in the hydro station. It is not to be expected that power can be generated at anything less than \$15 per kw-year and would likely be \$20 or more. To these figures must be added the cost of transmission losses which will be approximately 25 per cent. The cost for \$15 power when delivered over the 500-mile line will then be \$48 per kw-year and of \$20 power \$54 per kw-year.

On the basis of mils per kw-hr. for 7200-hour load these figures reduce to 6.6 mils for \$15 power and 7.5 mils for \$20 power. To these figures must be added an amount necessary to take the power from the low side of the receiving station of the hydro system to a point where a competing steam plant might be placed, and it is very doubtful if the hydro power on this basis can compete with steam power unless the price of coal increases materially above the present-day value.

As the 80,000 kw. per circuit 60-cycle line is questionable from the economic point of view, the problem immediately arises as to how to increase the capacity of the line and lower its cost per kw.

Higher voltages have been considered but there is a strong indication that the increase in carrying capacity is about equalled by the increase in cost.

Another scheme of increasing the line carrying capacity is to divide the conductors as suggested by Mr. Percy Thomas. This will increase the capacity of the line approximately 50 per cent and may be the answer to the problem. Operating engineers, however, have shied at the difficulties involved in operating a split-conductor line as they think they have enough troubles with one wire on an insulator string.

Another alternative which involves the use only of standard equipment and methods is to use a lower frequency. A 25-cycle 500-mile line is equivalent to a 60-cycle 200-mile line and no one would worry about such a line. With slightly leading power factor 150,000 kw. can be carried over one circuit with ample margin for a sudden increase in load and there is no question of stability in the same sense as with the 60-cycle line with equivalent load. Twenty-five cycles has been avoided as the main load in the industrial districts is 60 cycles and unquestionably the growth is in that direction and should by all means be encouraged. It is necessary then to convert the 25-cycle power to 60 cycles and charge the cost of transmission with frequency changers and their losses. Assuming the losses to be 10 per cent, the useful power delivered will be 135,000 kw. per circuit instead of 150,000 just mentioned. On this basis I have figured the cost of delivering 60-cycle power into the metropolitan district and find that it can be done for 6 mils for \$15 hydro power and 7 mils for \$20 power. These figures include the cost of one transformation after going through the frequency changers and if it is necessary to make an additional transformation the comparison is not quite so favorable to the long line. However, they are on the same basis as the figures given above for the 60-cycle transmission and they show about 10 per cent lower cost. This percentage difference is somewhat disappointing as the margin is not sufficient to assure one that the hydro power can compete with steam. It is, however, sufficient to warrant a very close analysis for any particular undertaking, as some slight difference in assumption might throw the balance heavily on one side of the other. For instance, if any large part of the power could be used at 25 cycles, the cost and losses in the frequency changers would be reduced, with a consequent advantage for the hydro system.

Frederick E. Terman: The influence of circuit constants on the performance of the transmission line as reflected in the circle-diagram coefficients can be clearly shown by expressing these coefficients in their simplest hyperbolic form, and expanding the result into a power series. Dropping the unimportant terms, and judiciously combining the others leads to a very simple expression.

Expressed in the simplest form, the conjugate expressions of the Evans and Sels diagram coefficients become, in the case of the transmission line alone:

$$1 = \text{Real part of } (A/B) = \text{Re}\,\frac{\coth + \theta}{Z_o}$$

$$\text{m} = \text{Imag. part of } (A/B) = \text{Imag}\,\frac{\coth \theta}{Z_o}$$

$$\text{n} = \text{Modulus } (1/B) = \text{Mod}\,\frac{\text{cosech}\, \theta}{Z_o}$$

Taking R, X, and Y as the total resistance, reactance, and admittance of the line, and remembering that a term of the character $X\,Y$ is dependent only upon the frequency and length, but is independent of the physical arrangements due to the reciprocal relation of capacity and inductance of open air lines, the following results are obtained:

$$1 = \frac{k}{(R^2 + X^2)^{\frac{1}{2}}}$$

$$m = \frac{R}{R^2 + X^2}$$

$$n = \frac{X}{R^2 + X^2} - k''\,Y$$

$k = \{ 1 + 1.133 \times 10^{-9} f^2 L^2 s \, (2 + 1.133 \times 10^{-9} f^2 L^2 s) \}^{\frac{1}{2}}$
$s = (0.1667 + 0.0221 \times 10^{-9} f^2 L^2)$
f = frequency
L = length of line in miles
$k'' = (0.333 + 0.0252 \times 10^{-9} f^2 L^2)$

For lines not exceeding 500 miles these results are accurate to within 1 per cent for open-air lines at commercial frequencies, (not over 60 cycles), and furnish an easy and yet sufficiently accurate method for the determination of the circle constants. In the ordinary line R/X is small, so we see that changing R does practically nothing to the circle diagram except alter m in proportion, while a change in X affects all of the coefficients. Furthermore, it is seen that Y is only a secondary influence since the term $k'' Y$ is not of great size.

In general the characteristic one would like are: (1) A large $(n - m)$, which gives a high power limit; and (2) a small $m/1$ which gives a line requiring only a minimum of variation in synchronous capacity from no-load to full load transmission. These requirements show the desirability of first a low reactance, and next a low resistance, although the change in characteristics is not great after the conductor section increases beyond a reasonable size.

Prof. Bush has called my attention to the fact that R, X, and Y can be expressed as functions of conductor spacing and diameter, making it possible to draw a set of curves showing the relation between the physical and electrical constants of the line. This has been done in Fig. 30 for a copper conductor, and using the data for R, X, and Y taken from the Westinghouse Reprint 82.

Before the present form of the Evans and Sels circle diagram becomes too well established, it would be well to call attention to the fact that plotting leading kv-a. in the lagging position leads to several conflicts with the customary conventions.

This point becomes evident by an examination of Fig. 31, which is in general similar to the diagrams of Thielman and Holladay[2]. In the original form this diagram is suited only for constant receiver potential since it depends upon the fact that the power

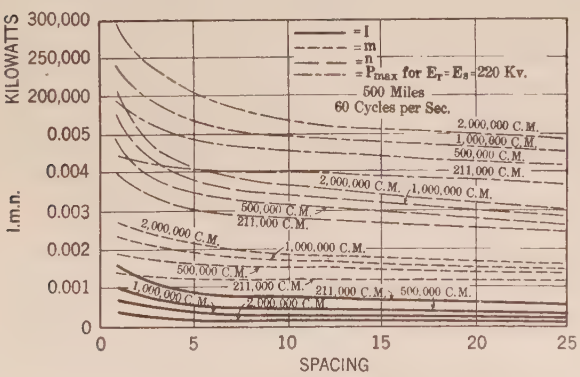

FIG. 30—INFLUENCE OF WIRE SPACING ON CIRCLE COEFFICIENTS

can be measured by the received current. To make this diagram suitable for other received voltages one can either (1) change the power scale, or (2) alter the voltage scale sufficiently to keep the power unit the same. The latter method is of course the practical one, and is carried out in Fig. 31 where the power scale is kept constant, and the potential unit varies with E_R, causing the point A to vary in position as $(E_R)^2$. Upon turning Fig. 31 at right angles to its present position the result is the Evans and Sels diagram with leading kv-a. plotted leading. On the other hand, if Fig. 31 is being drawn with all vectors of the diagram rotating in the negative sense, the result is the Evans and Sels diagram as is presented in the present paper.

2. Thielman, *Rev. Gen. d'El.* 1920-1921.
Holladay, A. I. E. E. 1922.

This inconsistency was justified in an earlier paper[3] of the present writers by the fact that inductive impedanceis $r + j x$, but analysis shows this to be an argument on the other side. If the equation given by Evans and Sels for the circles in terms of power is divided by E_R^2 an interesting, and for some purposes, very valuable circle diagram in terms of current results, but with the $+ Q$ taken as lagging, then lagging current must be plotted leading. Again dividing by E_R^2 gives the circle diagram in terms of admittance, where with the convention adopted by the writers, $g + j b$ represents inductive admittance, clearly not in agreement with inductive impedance as $r + j x$.

Putting the center of the circles in the second quadrant as in Fig. 31, and plotting leading kv-a. leading has the great advantage of avoiding all of these inconsistencies, and conforming to the common custom.[4]

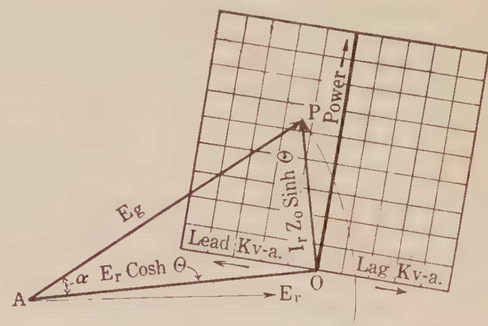

FIG. 31—VECTOR BASIS OF EVANS AND SELS CIRCLE DIAGRAM

C. A. Nickle: In the following, a method is developed for calculating the maximum power under steady state for a system comprising generators, transmission line, synchronous condensers and receiving circuit. This method has been developed on the assumption that saturation in the generator does not exist to any significant degree, although it may exist to any known degree in the condensers. Saturation in the generators would increase the maximum power over the values thus calculated.

The general equations of a transmission line having distributed inductance, capacity, resistance, and leakage are:

$$\dot{E} = \dot{E}_R \cos \beta 1 \cosh \alpha 1 + j \dot{E}_R \sin \beta 1 \sinh \alpha 1 + \dot{I}_R \sqrt{\frac{Z}{Y}} \cos \beta 1 \sinh \alpha 1 + j \dot{I}_R \sqrt{\frac{Z}{Y}} \sin \beta 1 \cosh \alpha 1 \quad (1)$$

$$\dot{I} = \dot{I}_R \cos \beta 1 \cosh \alpha 1 + j \dot{I}_R \sin \beta 1 \sinh \alpha 1 + \dot{E}_R \sqrt{\frac{Y}{Z}} \cos \beta 1 \sinh \alpha 1 + j \dot{E}_R \sqrt{\frac{Y}{Z}} \sin \beta 1 \cosh \alpha 1 \quad (2)$$

where

$\dot{E}_R$ = receiver voltage line to neutral
$\dot{I}_R$ = receiver current per phase
Z = line impedance per phase per mile
Y = line admittance to neutral per phase per mile
α = attenuation constant $= \sqrt{\tfrac{1}{2} (z y + r g - b x)}$
β = propogation constant $= \sqrt{\tfrac{1}{2} (z y - r g + b x)}$
1 = distance to any point on the line measured from the receiver end.
$\dot{E}$ = voltage to neutral 1 mile from receiver.
$\dot{I}$ = current 1 mile from the receiver.

For the 500-mile line under discussion the line constants expressed in per cent (as a fraction) on the basis of 100,000 kv-a. at 22 kv. are:

3. Evan & Sels in the "*Electric Journal*" 1921.
4. J. R. Dunbar in discussion on page 789 of 1922 A. I. E. E. TRANSACTIONS, on the vector representation of reactive power.

$$\sqrt{\frac{Z}{Y}} = 0.793 - j\,0.0501$$

$$\sqrt{\frac{Y}{Z}} = 1.26 + j\,0.0796$$

$$\alpha = 0.000131$$
$$\beta = 0.00207$$
$$\alpha\, l = 0.0655$$
$$\beta\, l = 1.035$$
$$\cosh \alpha\, l = 1.002$$
$$\sinh \alpha\, l = 0.0655$$
$$\cos \beta\, l = 0.515$$
$$\sin \beta\, l = 0.86$$

Substituting these constants in the general equations, we get the voltage and current expressed as a fraction of normal voltage and current, as follows:

$$E = 0.516\, E_R + j\,0.0563\, E_R + 0.0699\, I_R + j\,0.6813\, I_R \quad (3)$$
$$I = 0.516\, I_R + j\,0.0563\, I_R - 0.0261\, E_R + j\,10.089\, E_R \quad (4)$$

The receiver current expressed in terms of receiver power and receiver reactive kv-a. is

$$I_R = \frac{P}{E_R} + j\,\frac{Pj}{E_R} \qquad (5)$$

where

P = power per phase at receiver.
Pj = reactive kv-a. per phase at receiver.
E_R = receiver voltage per phase used as a reference vector.

Substituting (5) in (3) and (4)

$$E = 0.516\, E_R + 0.0699\,\frac{P}{E_R} - 0.6813\,\frac{Pj}{E_R}$$
$$+ j\left(0.0563\, E_R + 0.6813\,\frac{P}{E_R} + 0.0699\,\frac{Pj}{E_R}\right) \qquad (6)$$

$$I = -\,0.0261\, E_R + 0.516\,\frac{P}{E_R} - 0.0563\,\frac{Pj}{E_R}$$
$$+ j\left(1.089\, E_R + 0.0563\,\frac{P}{E_R} + 0.516\,\frac{Pj}{E_R}\right) \qquad (7)$$

The nominal e. m. f. of the generator is

$$E_n = E + j\, x_0 I \qquad (8)$$

where x_0 is the synchronous reactance of the generator.

Substituting (6) and (7) in (8)

$$E_n = \Big[\,(0.516 - 1.089\, x_0)\, E_R$$
$$+ \left(0.0699 - 0.0563\, x_0\right)\frac{P}{E_R} - \left(0.6813 + 0.0516 x_0\right)\frac{Pj}{E_R}\Big]$$
$$+ j\Big[\,(0.0563 - 0.0261\, x_0)\, E_R$$
$$\left(0.6813 + 516\, x_o\right)\frac{P}{E_R} + \left(0.0699 - 0.563\, x_o\right)\frac{Pj}{E_R}\Big] \qquad (9)$$

Expressing in absolute values, dividing through by E_R^2, completing the squares, and rearranging,

$$\left[\frac{P}{E_R^2} + \left(\frac{0.0745 - 0.0939\, x_0 + 0.0478\, x_0^2}{0.4688 + 0.6941\, x_0 + 0.2692\, x_0^2}\right)\right]^2$$
$$+ \left[\frac{Pj}{E_R^2} + \left(\frac{-0.3476 + 0.4706\, x_0 + 0.560\, x_0^2}{0.4688 + 0.6941\, x_0 + 0.2692\, x_0^2}\right)\right]^2$$
$$= \frac{E_n^2}{E_R^2}\left[\frac{1}{0.4688 + 0.6941\, x_0 + 0.2692\, x_0^2}\right] \qquad (10)$$

Equation (10) is the equation of a family of circles having a parameter $\dfrac{E_n}{E_R}$

and coordinates $\dfrac{Pj}{E_R^2}$ and $\dfrac{P}{E_R^2}$. Thus the center of these circles is located at

$$\frac{Pj}{E_R^2} = -\left[\frac{-0.3476 + 0.4706 x_0 + 0.560\, x_0^2}{0.4688 + 0.6941\, x_0 + 0.2692\, x_0^2}\right] \qquad (11)$$

$$\frac{P}{E_R^2} = -\left[\frac{0.0745 - 0.0939 x_0 + 0.0478\, x_0^2}{0.4688 + 0.6941 x_0 + 0.2692\, x_0^2}\right] \qquad (12)$$

The radii are given by

$$R = \frac{E_n}{E_R}\sqrt{\frac{1}{0.4688 + 0.6941\, x_t + 0.2692\, x_0^2}} \qquad (13)$$

For any given generator, x_0 is known, and one set of concentric circles will give the performance of the line.

The condition $x_0 = 0$ represents an infinite generator, and a set of circles for this condition may be used for determining the voltage at the generator terminals. Fig. 32 shows a family of

Fig. 32—500-Mile Line. 0 Per Cent Gen. Synchronous Reactance. 100,000 Kv-a. Base. 220 Kv.

circles for $x_0 = 0$ and Fig. 33 for $x_0 = 0.50$, which corresponds approximately to a 200,000 kv-a. generator. The method of obtaining the maximum power which can be transmitted over a 500-mile straightaway line from these curves is as follows:

For any given receiver power, the reactive kv-a. in the line at the receiver, required to hold normal voltage at both the receiving and sending ends, is obtained from the set of curves for $x_0 = 0$. For these conditions $E_R = 1.0$ and $\dfrac{E_n}{E_R} = 1.0$.

Having found the reactive kv-a. required at the receiver, the excitation on the receiving condenser can be obtained from the condenser characteristics. A typical set of these characteristics is shown in Fig. 34.

Thus for any receiver power setting, the receiver reactive kv-a. and receiver power are known, and from the curves for $x_0 = 0.50$, the approximate excitation on the generator may be read directly.

The variation of receiver voltage with receiver power is then obtained under the assumption that the generator and condenser

excitation remain fixed. To obtain this variation, a new receiver voltage is assumed. For this new receiver voltage, a new value of $\frac{Pj}{E_R^2}$ is obtained from the condenser characteristics and the new value of $\frac{E_n}{E_R}$ is known. Hence from the curves for $x_0 = 0.50$ the new value of $\frac{P}{E_R^2}$ is obtained.

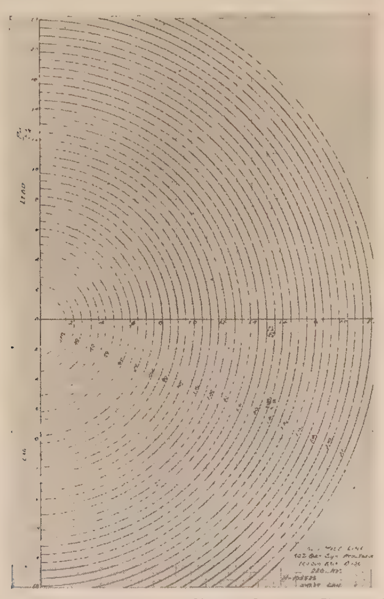

FIG. 33—500-MILE LINE. 50 PER CENT GEN. SYNCHRONOUS REACTANCE. 100,000 KV-A. BASE. 220 KV.

Repeating this process for several assumed values of E_R, a curve may be plotted with P_R as abscissae and E_R as ordinates. The maximum power for these conditions occurs at the point where $\frac{d\,P}{d\,E_R} = 0$ and the maximum power of the line under

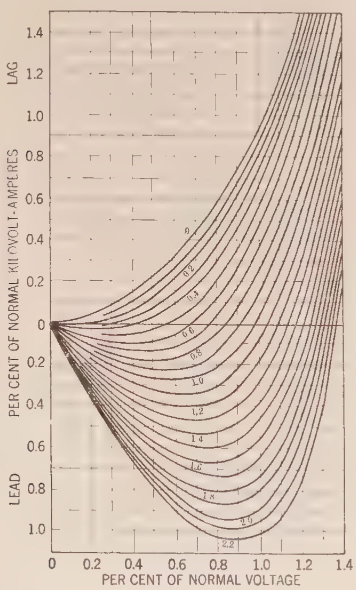

FIG. 34

steady conditions occurs for the settings which give $\frac{d\,P}{d\,E_R} = 0$ for $E_R = 1.0$.

Fig. 35 shows a set of such curves obtained for a 500-mile line under the following assumptions:

75,000-kv-a. condenser at receiver.
Generator synchronous reactance $x_0 = 0.50$
Generator synchronous reactance $x_0 = 0$
Unity power factor motor load.

The solid curves are for $x_0 = 0.50$ and the dotted curves for

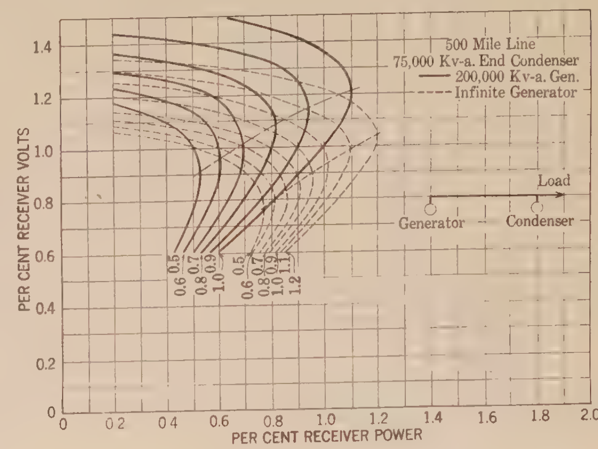

FIG. 35

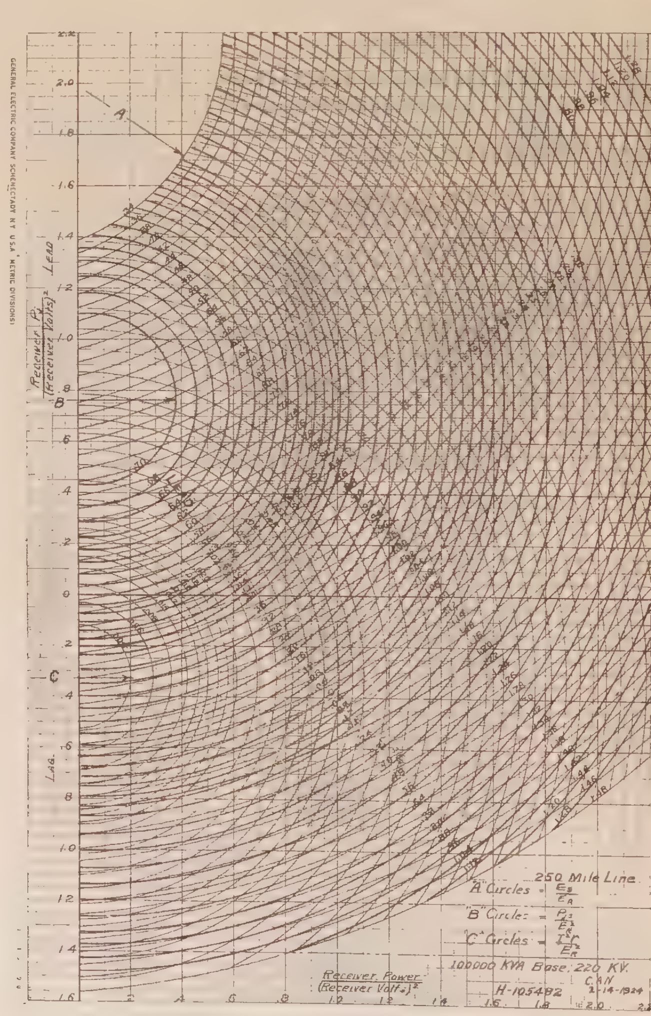

FIG. 36

$x_0 = 0$. For $x_0 = 0$, $\frac{d\,P}{d\,E_R}$ is zero for $E_R = 1.0$ at approximately 117,000 kw. and, for $x_0 = 0.50$, at approximately 67,000 kw. With the finite generator assumed the maximum power is thus 57 per cent of that which could be obtained with an infinite generator.

Sectionalized Line

The process of obtaining these curves for a system having a condenser located at the middle of the line is considerably more difficult. For this case, separate computations are necessary for each 250-mile section. Curves, similar to those drawn for the 500-mile line, are obtained for a 250 mile line, and in addition, circles giving line loss and reactive kv-a. at the sending end are drawn for the condition $x_0 = 0$. These are shown in Figs. 36 and 37 and are derived as follows:

For the 250 mile line, the line constants are

$$\sqrt{\frac{Z}{Y}} = 0.793 - j\,0.0501$$

$$\sqrt{\frac{Y}{Z}} = 1.26 + j\,0.0796$$

$$\begin{aligned} \alpha &= 0.000131 \\ \beta &= 0.00207 \\ \alpha\, l &= 0.0327 \\ \beta\, l &= 0.517 \\ \cosh \alpha\, l &= 1.001 \\ \sinh \alpha\, l &= 0.0327 \\ \cos \beta\, l &= 0.87 \\ \sin \beta\, l &= 0.493 \end{aligned}$$

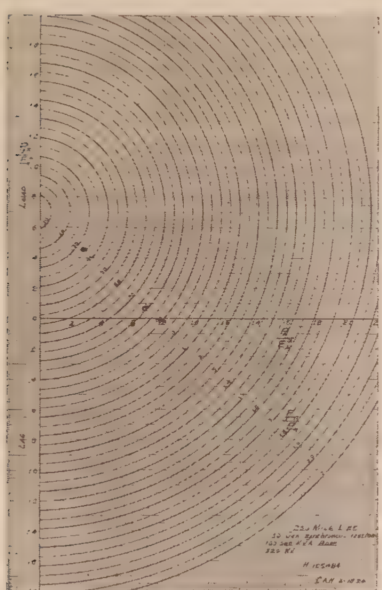

Fig. 37—250 Mile Line 0.50 Gem Synchronous Reactance, 100,000 Kv-a Base 220 Kv.

Substituting these constants and equation (5) in the general equations (1) and (2) we get

$$\dot{E}' = 0.87\,E_R + 0.0473\,\frac{P}{E_R} - 0.389\,\frac{Pj}{E_R} + j\left(0.0161\,E_R + 0.389\,\frac{P}{E_R} + 0.0473\,\frac{Pj}{E_R}\right) \qquad (14)$$

$$\dot{I} = -\,0.00345\,E_R + 0.87\,\frac{P}{E_R} - 0.0161\,\frac{Pj}{E_R} + j\left(0.620\,E_R + 0.0161\,\frac{P}{E_R} + 0.87\,\frac{Pj}{E_R}\right) \qquad (15)$$

Telescoping (14) and (15) for power at the sending end.

$$P_s = \dot{E}\,\dot{I}$$
$$= 0.007\,E_R^2 + P + 0.0306\,Pj + 0.0474\,\frac{P^2}{E_R^2} + 0.0474\,\frac{Pj}{E_R^2} \qquad (16)$$

The line loss is the difference between the power at the sending end and the power at the receiving end or

$$P_L = 0.007\,E_R^2 + 0.0306\,Pj + 0.0474\,\frac{P^2}{E_R^2} + 0.0474\,\frac{Pj^2}{E_R^2} \qquad (17)$$

Dividing through by E_R^2, completing the squares and rearranging,

$$\left(\frac{P}{E_R^2}\right)^2 + \left(\frac{Pj}{E_R^2} + 0.343\right)^2 = \frac{21.1\,P_L}{E_R^2} - 0.0430 \qquad (18)$$

This is the equation of a family of circles of radii,

$$R = \frac{21.1\,P_L}{E_R^2} - 0.0430 \qquad (19)$$

and the center at

$$\frac{Pj}{E_R^2} = -\,0.343 \qquad (20)$$

$$\frac{P}{E_R^2} = 0 \qquad (21)$$

The reactive kv-a. at the sending end is the magnitude of the cross product of (14) and (15). Thus

$$Pj_s = 0.540\,E_R^2 + 0.0306\,P + 0.516\,Pj - 0.337\,\frac{P^2}{E_R^2} - 0.337\,\frac{Pj^2}{E_R^2} \qquad (22)$$

Dividing through by E_R^2, completing the squares and rearranging,

$$\left(\frac{P}{E_R^2} - 0.0454\right)^2 + \left(\frac{Pj}{E_R^2} - 0.765\right)^2 = 2.193 - 2.97\,\frac{Pj_s}{E_R^2} \qquad (23)$$

This is the equation of a family of circles of radii

$$R = \sqrt{2.193 - 2.97\,\frac{Pj_s}{E_R^2}} \qquad (24)$$

and the center at

$$\frac{Pj}{E_R^2} = 0.765 \qquad (25)$$

$$\frac{P}{E_R^2} = 0.0454 \qquad (26)$$

The nominal e. m. f. of the generator is

$$\dot{E}_n = \dot{E} + j\,x_0\,\dot{I} \qquad (8)$$

Substituting (14) and (15) in (8)

$$\begin{aligned} \dot{E}_n = &\left[(0.87 - 0.62\,x_0)\,E_R + (0.0473 - 0.0161\,x_0)\,\frac{P}{E_R} - (0.389 + 0.87\,x_0)\,\frac{Pj}{E_R}\right] \\ &+ j\left[(0.0161 - 0.00345\,x_0)\,E_R + (0.389 + 0.87\,x_0)\,\frac{P}{E_R} + (0.0473 - 0.0161\,x_0)\,\frac{Pj}{E_R}\right] \end{aligned} \qquad (27)$$

Expressing in absolute values, dividing through by E_R^2, completing the squares, and rearranging,

$$\left[\frac{P}{E_R^2} + \left(\frac{0.0478 - 0.0306\,x_0 + 0.007\,x_0^2}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}\right)\right]^2 + \left[\frac{Pj}{E_R^2} + \left(\frac{-\,0.338 - 0.516\,x_0 + 0.54\,x_0^2}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}\right)\right]^2 = \frac{E_n^2}{E_R^2}\left[\frac{1}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}\right] \qquad (28)$$

This is the equation of a family of circles of radii.

$$R = \frac{E_n}{E_R}\sqrt{\frac{1}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}} \qquad (29)$$

and the center at

$$\frac{Pj}{E_R^2} = -\left(\frac{-0.338 - 0.516\,x_0 + 0.54\,x_0^2}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}\right) \qquad (30)$$

$$\frac{P}{E_R^2} = -\left(\frac{0.0478 - 0.0306\,x_0 + 0.007\,x_0^2}{0.1537 + 0.676\,x_0 + 0.757\,x_0^2}\right) \qquad (31)$$

In Fig. 36, circles are drawn giving reactive kv-a. at the sending end, voltage at the sending end, and line loss.

In Fig. 37, generator nominal voltage circles are given for a generator synchronous reactance $x_0 = 0.50$.

The sectionalized 500-mile line may be represented by two 250-mile sections in series as shown in Fig. 38.

The reactive kv-a. at D required to give normal voltage at C and D can be obtained from Fig. 36. From this reactive kv-a. the excitation required on the receiving condenser C_2 can be obtained from the condenser characteristics, Fig. 34. The power and reactive kv-a. at C may also be obtained from Fig. 36. The power at B is the same as the power at C excepting the losses in the condenser C_1. If the condenser losses are significant, they should be added to the power at C to obtain the power at B. The power at B, thus obtained, is the receiver power for the section $A\ B$ and from Fig. 36 we can get the reactive kv-a. required at B to hold normal voltage at A and B. The difference

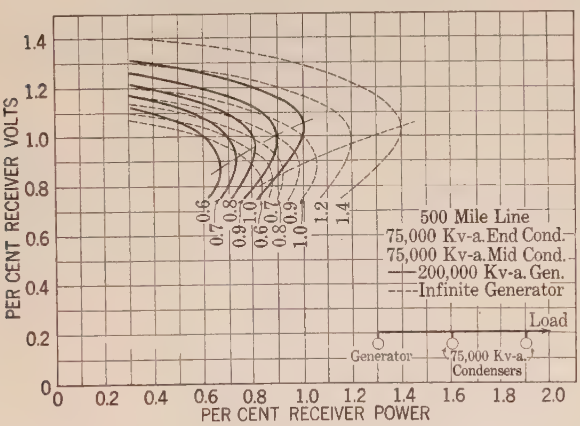

FIG. 38

between the reactive kv-a. required at B and the reactive kv-a. at C, due to the load at D, gives the reactive kv-a. which the condenser C_1 must furnish.

The excitation on the condenser C_1 is then found from the condenser characteristics, Fig. 34. From the values of power and reactive kv-a. at B, the generator excitation can be obtained from Fig. 37.

Next, assume a new value of power at D. Then assume three or four different values of voltage at D, with the assumed new value of power. For each of the assumed voltage at D, the power and reactive kv-a. at D are known since the excitation on the condenser C_2 is assumed to remain fixed. From these values of power and reactive kv-a. the voltage, power, and reactive kv-a. at C can be obtained from Fig. 36. Then from the voltage at C and the known excitation on the condenser C_1 the reactive kv-a. furnished by this condenser is found from the condenser characteristics, Fig. 34. The reactive kv-a. at B is then the sum of the kv-a. at C and the condenser kv-a.

Thus, for each assumed voltage at D, the power conditions at B are found, and, since these are the receiver conditions for the section $A\ B$, the excitation required on the generator G to give these conditions is found from Fig. 37.

The values of generator nominal voltage thus obtained are plotted against the assumed values of receiver voltage at D and that point on the curve, where the generator nominal voltage is the same as the value previously obtained, gives the correct value of receiver volts which correspond to the power assumed at D. This process is repeated for different assumed values of receiver power at D and a curve is plotted with receiver power as abscissae and receiver volts as ordinates. Similar curves are drawn for different power settings, and that power setting which gives $\frac{d\,P}{d\,E_R} = 0$ for $E_R = 1.0$ is the maximum power that can be transmitted over the line at $E_s = 1.0$.

In Fig. 38 curves are shown for a sectionalized 500-mile line for the following assumptions;

75,000 kv-a. condenser at receiver.
75,000 kv-a. condenser at mid-point.
Generator synchronous reactance $x_0 = 0.50$.
Generator synchronous reactance $x_0 = 0$
Unity power factor load at receiver.

The maximum power for an infinite generator is thus 130,000 kw. and for the finite generator, 90,000 kw.

E. A. Smith: In referring to the paper on Superpower Transmission, I have noticed that Mr. Thomas has brought up some interesting points, such as I had recently figured on and by following Mr. Harold Goodwin, Jr. in his paper on Qualitative Analysis of Transmission Lines, a thorough analytical study can be made covering the general principles of very high tension transmission problems.

I doubt very much if the average engineer can solve and foresee the many difficulties encountered with 250 and 500-mile transmission systems of the 220,000 or higher voltage type.

The capacity of the transmission lines as well as the voltage regulation required for each particular system has to be taken into consideration to solve the principle factors from the performances on the systems as outlined under all conditions to operate efficiently. The different loads on a transmission system as well as the heating effects and losses have to be expounded in a way to cover the starting and stopping of the necessary apparatus at the distributing centers.

The costs of a system have to be studied in two ways, namely, construction and operation and by putting a system into operation, the best economical results are required to produce the means to cover these two principles. The period of construction being only of a short duration, it must be overlooked after completion, if the entire system is on a satisfactory operating basis.

Owing to the many theoretical assumptions for high voltages of this kind, a series of complications will arise in time, causing many difficult problems to appear on these systems at enormous expense and to keep the receiving end supplied, studies will have to be undertaken to analyze thoroughly all the principles involved in generation and transmission to bring out such points of interest which will help eliminate all unnecessary troubles and expenses.

I think Mr. Thomas is quite right in his assumption of installing a stepdown station in the center of the transmission system, by placing synchronous condensers therein, and providing for automatic means of fixing the potential which at the same time would divide the system entirely into two separate sections or lines. This would make the system more expensive as far as construction is concerned, but in the end would pay for itself.

I feel that the transmission system at 220,000 volts will not be able to stand up under all maximum load and weather conditions for any great length of time as the qualities of the conductors are not up to the point of satisfaction to withstand the continuous heat factors.

As a matter of fact the load at the receiving ends must be supplied at a fixed voltage and power factor and the synchronous condensers must be arranged to operate automatically to deliver

the leading or lagging kv-a. as required, otherwise if this is not provided, the voltage will change accordingly to load conconditions and losses. It will be seen by referring to Figs. 1, 2, 3 and 4, the curves will also change accordingly, owing to the fluctuating conditions of the load, voltage and losses which take place on long transmission lines, whereas on short-distance lines the losses would be considerably reduced and better operation would result. From this point it will be seen, that by introducing a central stepdown station at the middle of the transmission system, the line losses would be reduced at different loads.

According to calculations it is noted that with a maximum output of the generators, the power factor will be nearly unity, but due to many changes in the load, it will be unable to retain this value and the losses will be greater.

Assuming that all the curves in Figs. 1, 2, 3 and 4 and the values in Table A are correct, we have to compare them with actual practice, although, they appear to be fair values in connection with this superpower transmission when operating under no-load and full-load conditions.

E. A. Smith: In reference to Messrs. Evans and Sels paper although the curves represent certain conditions for a transmission system, the details are more or less based on theoretical assumptions.

It is seen that the curves are plotted according to the conditions of the load and voltage of the system and depend mostly upon the resistance, reactance and impedance of the circuits described. By following the diagrams as shown it is readily seen that the synchronous condenser capacity required for any load at the receiver end, can be determined for approximate values at different power factors, but if the supply voltage varies between wide limits the radius of the receiver circle changes, which offsets the assumed fixed values and results in greater transmission losses for the length of the line.

Although the receiver load must retain a fixed power factor and is also assumed to act as an impedance across the circuit, it must have synchronous apparatus available for maintaining the voltage and controlling the power factor at the receiver end, to increase the power limit.

For any long transmission system, the most suitable arrangement would be, a synchronous condenser station at the center of the system in which the synchronous apparatus would tend to help regulate the voltage up to the maximum power limit.

As this system will include all kinds of electrical equipment as well as rotating apparatus, the system will be subjected to voltage fluctuations at different periods of the day (due to load conditions) and so will cause the rotating apparatus to fall out of step when the voltage drops below its fixed minimum value.

Professor V. Karapetoff: For the last year or so, we have been constructing at Cornell University a mechanical device to imitate the performance of a long transmission line. This device consists of pivoted weights and of springs, each weight taking the place of the inductance of a small section of the line and each spring representing the capacitance of that section. We are practically ready now to assemble this apparatus and then we shall have to provide a device for communicating to it sinusoidal vibrations to imitate the generator, and a load consisting perhaps of a friction disk, a spring, and a flywheel. Such a mechanical device is subject to the same equations of motion as a transmission line, under any desired transient conditions. Therefore, no mathematics is necessary: All you have to do is to impose a desired mechanical condition upon that model and to observe what happens. The natural frequency of vibration of each element is several seconds so that it is easy to follow a transient along such a line with a naked eye.

The authors of the papers use the method of complex quantities, and I should be the last one to deprecate it or to speak against this method, having used it so much myself. However, we now have to make another step, namely, in the direction of the so-called vector analysis. In the JOURNAL for last December I have a little article on the application of vector analysis to the circle diagrams of certain types of a-c. machines, principally commutator motors, and I urge the use of vector analysis, especially of the scalar product and of the factor product of two vectors, in the study of transmission lines under steady conditions.

In view of the importance which the circle diagram of power has acquired of late, it seems advisable to reduce its proof to the simplest possible terms, in order to make its use more general. The authors use the familiar method of complex quantities; in the case of power this necessitates a multiplication of a voltage by a current which is conjugate of the actual current. In other words, they use the relationship $P + j\,Q = (e + j\,e')\,(i - j\,i') = (e\,i + e'\,i') + j\,(e'\,i - e\,i')$ (11)

While this method is perfectly legitimate and leads to correct results[5], it is also of interest to solve the same problem using the principles of *Vector Analysis.* This branch of mathematics has not been used much as yet in electrical engineering, although its use has been found of great advantage in many branches of physics and mechanics. Since the theory of electrical engineering is largely based on these sciences, it is only a question of time when Vector Analysis will find its place in engineering investigations.[6]

Referring to Fig. 39, let vectors of voltages and currents be drawn in the $X\,Y$ plane. Let unit vectors parallel to the X and Y axis be donated by **x** and **y** respectively. Then a current vector and a voltage vector may be written in the following form:

$$\mathbf{E} = \mathbf{x}\,e + \mathbf{y}\,e' \qquad (12)$$

$$\mathbf{I} = \mathbf{x}\,i + \mathbf{y}\,i' \qquad (13)$$

Vector quantities are denoted by bold-face letters, scalar quantities by italics.[7]

In Vector Analysis two kinds of products of two vectors **M** and **N** are distinguished: the *scalar product* (or the dot product)

$$\mathbf{M} \cdot \mathbf{N} = M\,N \operatorname{Cos} \theta \qquad (14)$$

and the *vector product* (or the cross product)

$$\mathbf{M} \times \mathbf{N} = \mathbf{q}\,M\,N \operatorname{Sin} \theta \qquad (15)$$

in these expressions θ is the angle between the vectors **M** and **N**, and **q** is a unit vector in a direction normal to the $X\,Y$ plane (see figure)

From these definitions we may write

$$\mathbf{x} \cdot \mathbf{x} = \mathbf{y} \cdot \mathbf{y} = 1; \mathbf{x} \cdot \mathbf{y} = 0 \qquad (16)$$

$$\mathbf{x} \times \mathbf{x} = \mathbf{y} \times \mathbf{y} = 0; \mathbf{x} \times \mathbf{y} = -\,\mathbf{y} \times \mathbf{x} = \mathbf{q} \qquad (17)$$

These expressions follow from eqs. (14) and (15), by putting $\theta = 0$ or $\theta = 90°$, and $M = N = 1$. Forming a scalar vector product of eqs. (12) and (13), we get

$$\mathbf{I} \cdot \mathbf{E} = \mathbf{x} \cdot \mathbf{x}\,i\,e + \mathbf{y} \cdot \mathbf{y}\,i'\,e' + \mathbf{x} \cdot \mathbf{y}\,(e\,i' + i\,e') \qquad (18)$$

Using eqs. (16), we find that

$$P = \mathbf{I} \cdot \mathbf{E} \qquad (19)$$

In other words, the real power is equal to the scalar product of the current and voltage vectors. This also follows directly from the expression $P = I\,E \operatorname{Cos} \phi$, which is identical with the definition (14).

Similarly, forming a vector product (cross product) of eqs. (12) and (13), we obtain:

$$\mathbf{I} \times \mathbf{E} = \mathbf{q}\,(i\,e' - i'\,e) \qquad (20)$$

In other words, the reactive power

$$\mathbf{Q} = \mathbf{I} \times \mathbf{E} \qquad (21)$$

Thus **Q** may be represented by a vector normal to the $X\,Y$ plane. Since for any combination of values of **E** and **I**, **Q** is always normal to the $X\,Y$ plane, this result is not objectionable on the score that reactive power cannot be a vector. It is a vector which always is in the same direction, or which for a certain range of

5. For a deduction of the terms on the right-hand side of this equation, see for example, V. Karapetoff, "The Electric Circuit," pp. 91 and 92.

6. As a beginning in this direction, the present writer has recently published an article entitled "The Use of the Scalar Product of Vectors in Locus Diagrams of Electrical Machinery," this JOURNAL, 1923, Vol. 842, p. 181.

7. For an elementary exposition of the general principles of the subject see, for example, J. G. Coffin's "Vector Analysis" (Wiley).

values of angle ϕ may be negative, but which is always normal to the plane in which $\mathbf{E}$ and $\mathbf{I}$ are drawn.

It is convenient to consider P and Q as orthogonal components of a vector, say $\mathbf{U}$. so that

$$\mathbf{U} = \mathbf{p}\,P + \mathbf{q}\,Q \qquad (22)$$

where $\mathbf{p}$ and $\mathbf{q}$ are unit vectors at right angles to each other. But $\mathbf{q}$ is perpendicular to the $X\ Y$ plane; hence $\mathbf{p}$ lies in that plane, as shown in the Fig. 39. The exact position of the P axis with respect to the $X\ Y$ axis is immaterial; in fact the $P\ Q$ diagram can be drawn entirely separate from the $X\ Y$ diagram. Thus, from the foregoing theory we have for the supply power

$$\mathbf{U}_s = \mathbf{p}\,(\mathbf{I}_s \cdot \mathbf{E}_s) + \mathbf{I}_s \times \mathbf{E}_s \qquad (23)$$

Eliminating $\mathbf{I}_r$ from eqs. (1) in the paper, we get

$$B\,\mathbf{I}_s = A\,\mathbf{E}_s - \mathbf{E}_r \qquad (24)$$

which is equivalent to the first of the eqs. (2). Multiply eq. (24) separately by $\cdot\,\mathbf{E}_s$ and by $\times\,\mathbf{E}_s$ and substitute the results in eq. (23). This will give

$$B\,\mathbf{U}_s = \mathbf{p}\,(A\,\mathbf{E}_s \cdot \mathbf{E}_s - \mathbf{E}_r \cdot \mathbf{E}_s) + A\,\mathbf{E}_s \times \mathbf{E}_s - \mathbf{E}_r \times \mathbf{E}_s) \quad (25)$$

But, according to eqs. (14) and (15),

$$\mathbf{E}_s \,.\, \mathbf{E}_s = E_s^2;\ \mathbf{E}_s \times \mathbf{E}_s = 0 \qquad (26)$$

Hence

$$B\,\mathbf{U}_s = \mathbf{p}\,A\,E_s^2 - (\mathbf{p}\,\mathbf{E}_r \cdot \mathbf{E}_s + \mathbf{E}_r \times \mathbf{E}_s) \qquad (27)$$

The last equation may be simplified as follows:

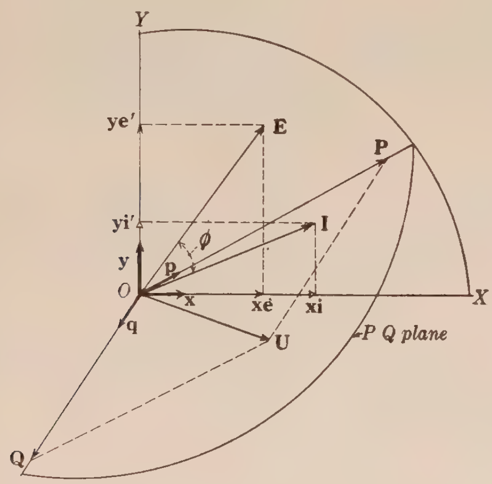

Fig. 39

$$\mathbf{p}\,\mathbf{E}_r \cdot \mathbf{E}_s + \mathbf{E} \times \mathbf{E}_s = (E_r\,E_s)\,(\mathbf{p}\,\mathrm{Cos}\,\theta + \mathbf{q}\,\mathrm{Sin}\,\theta) = (E_r\,E_s)\,\mathbf{r}_\theta \quad (28)$$

where $\mathbf{r}_\theta$ is a unit vector in the $P\ Q$ plant at an agnle θ to the P axis, and θ is the phase angle between $\mathbf{E}_r$ and $\mathbf{E}_s$. Thus, eq. (27) becomes

$$\mathbf{U}_s = \mathbf{p}\,(A/B)\,E_s^2 - (E_r\,E_s/B)\,\mathbf{r}_\theta \qquad (29)$$

Let E_s be kept constant; then the term $\mathbf{d} = \mathbf{p}\,(A/B)\,E_s^2$ is also constant. (A/B) is a complex quantity, which may be written in the form:

$$A/B = c\,\epsilon^{j\sigma}$$

Consequently, $\mathbf{d}$ is a vector of length $c\,E_s^2$, at an angle ∂ to the p axis.

The complex quantity B may be written in the form

$$B = b\,\epsilon^{j\tau} \qquad (31)$$

so that

$$(E_r\,E_s/B)\,\mathbf{r}\theta = (E_r\,E_s/b)\,\mathbf{r}_{\theta - \tau} \qquad (32)$$

which is a vector of length $E_r\,E_s/b$, at an angle $\theta - \tau$ to the p axis. If E_r is also kept constant, this term represents a circle of radius

$$R = E_r\,E_s/b \qquad (33)$$

The above expressions for $\mathbf{d}$ and R are identical with the values given in the paper for the position of the circle and its radius.

While the above deduction may seem long, its length is due to the general introduction on vector analysis. The specific problem to be solved begins with eq. (23) and ends with eq. (29), which is the desired equation of the circle when E_s and E_r are constant.

By assuming E_r to be variable and differentiating eq. (29) *vectorically* (that is, with respect to both $\mathbf{r}$ and θ), a new vector equation is obtained. Eliminating E_r between this equation and eq. (29), gives a vector equation of the envelope. It is not necessary to introduce the components $\alpha, \beta, \gamma, \delta$, and the awkward square roots of the sums of the squares.

C. M. Longbottom (**by letter**): I propose to discuss one or two aspects of long-distance transmission which were not brought out in the papers. Reference has been made by Messrs. Evans and Bergvall to the amount of reactive kv-a. required at the mid-point of the line when a synchronous condenser is placed there to maintain constant voltage at this point. It seems very pertinent that one should carry this discussion a little further in order to examine the conditions arising from such subdivision of the line and what is more important, to

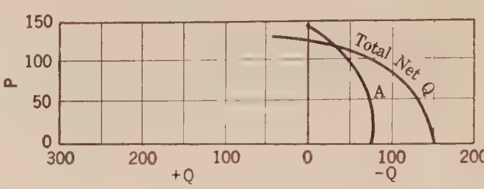

Fig. 40

determine how many subdivisions should be made in any case for the most economical arrangement of equipment.

With this object in view, I have examined four particular cases of a 500-mile transmission line operating at 220 kv. It was assumed that transformer banks of 200,000 kv-a. were situated at either end of the line. While banks of this rating would be too big in the case of an "unloaded" line as in case (1) outlined below, banks of this rating would be too small for case (4) but as this is an average value of the maximum load delivered it is not considered necessary to take different transformers in each case. This fact will not materially effect the conclusions to be drawn from this analysis.

The following four cases were considered; (1) a 500-mile transmission line with transformer banks at each end, ample

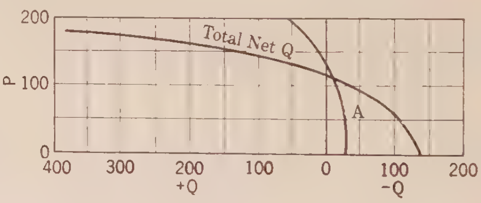

Fig .41

synchronous-condenser capacity at the receiver and ample generator capacity at the supply end. (2) The same line as in (1) but with a synchronous condenser stationed at the mid-point thus dividing the line into two equal portions and forming what we will term "nodal" points at the generator, the mid-point and the receiver end. (3) Similar to (1) but with four nodal points equally spaced or, in other words, two intermediate condenser stations. (4) As in (1) but with five nodal points equally spaced. It will be assumed that the voltage at nodal points is kept constant at 220 kv., that the synchronous condenser losses will be neglected and that the generator characteristics will also be neglected.

Figs. 40 and 41 represent the four cases outlined. In Fig. 40 is represented the variation in the net resultant reactive kv-a. injected into the system with variations in loads for a 500-mile line with two nodal points, that is, at the receiver and supply

ends. By net reactive kv-a. is meant the algebraic sum of the reactive kv-a. components delivered to the line at each nodal point. Thus in case (1) there will be delivered to the line approximately 150,000 kv-a. lagging, part of this being supplied by the generator and part by the condenser at the receiver end. At any other load the net resultant kv-a. can be read off from the curve.

Curve *A*, in all cases, refers to the generator characteristics and is actually the circle diagram for the supply end of the system. In Fig. 40 at no load it will be seen that there is nearly 80,000 kv-a. charging current to be supplied by the generator. This reactive kv-a. seriously effects the operation of the system since it tends to over-excite the generators so that the excitation of these machines must be very substantially reduced and this in

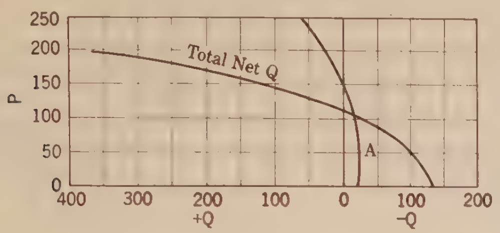

Fig. 42

itself presents a problem of no little difficulty. Reference to Figs. 41, 42 and 43 will show that in general the more nodal points, that is, synchronous condenser stations distributed along the system the less the generator excitation needs to be interfered with. It will be seen from Fig. 43 that with five nodal points the generator power factor differs very little from unity under any condition of load. It follows, therefore, that the best use is made of the generators when a large number of condenser stations are used. In other words, the rating of the generating equipment is higher under these conditions.

A question which is equally important with that of the generator is the amount of synchronous-condenser equipment that must be installed under the various conditions. This represents a capital cost which must be taken into account in the same way

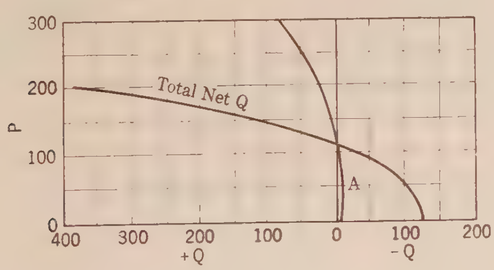

Fig. 43

as the cost of the conductors. In general, it might be said that a synchronous condenser placed at any point along such a line is less effective in regulating the voltage than one placed at the receiving end, due to the fact that the inductance between that station and the generator is less than that for the whole line.

The amount of reactive kv-a. supplied at the nodal points has no direct relation to the amount of plant required since leading kv-a. may be supplied at one point and lagging kv-a. at another as is shown in the accompanying tables. It must be pointed out that the total net kv-a. shown in Figs. 41 to 43 gives no indication of the power factor on the system. The curve is of more theoretical interest than practical. Fig. 44 shows this net reactive kv-a. for the four cases considered plotted for different values of kilowatts transmitted. As a matter of interest, it might be pointed out that the load curve for zero reactive kv-a. represents approximately the conditions mentioned by Mr. Percy H. Thomas on Page 2 of his paper. If resistance were neglected there would be no reactive kv-a. injected into the line for this particular line for this particular load. Although Fig. 40 shows that there is no net reactive kv-a. injected at 125,000 kw. nevertheless Table 1 shows that the generator is actually supplying 24,000 kv-a. and the receiver condenser is drawing 24,000 kv-a. The apparent discrepancy in Fig. 44

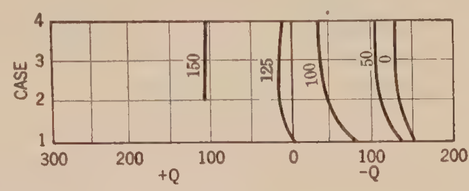

Fig. 44

from this purely theoretical consideration, is due to several causes among which are; first, the neglect of resistance in the theoretical case; secondly, the rise in voltage along the line in the practical case; and thirdly, possible inaccuracies in calculation as no great accuracy was aimed at in deriving these figures.

Tables I to IV show the amount of plant in synchronous condensers required for any particular number of nodal points. In general it might be said that the more nodal points give the greater amount of synchronous-condenser plant required but at the same time the load which may be transmitted over the line is increased. Fig. 45 is a purely theoretical analysis of the four cases considered. The maximum load referred to is the maximum possible load which would be transmitted over the line regardless of any questions of stability. This corresponds to the power limit of the line as originally mentioned by Mr. H. B. Dwight and others some time ago. And in general will be the limiting load of the first section of the line, that is, the generator end. This maximum load has been used to derive the curve showing the ratio between the total net reactive kv-a. and maximum power.

In summarizing the above discussion the following conclusions may be drawn:

1. The effect upon the generator excitation of increasing the number of nodal points in a long transmission line is to increase the stability of the generator at light load and, general to improve the power factor and hence increase the station capacity.

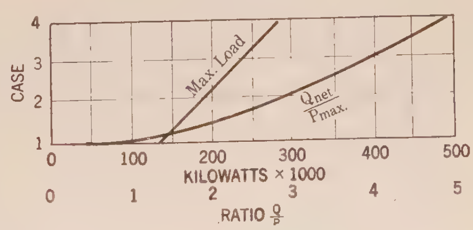

Fig. 45

2. An increase in the number of nodal points leads in general to an increase in the synchronous-condenser equipment required. At the same time the output of the line is materially increased.

I have purposely avoided discussing questions of stability as the characteristics of the load have such a direct bearing on this subject that each particular case must be considered on its merits. It is for this reason that I have chosen transformer banks of 200,000 kv-a., although actual stability limitations would call for transformer banks of approximately half this rating.

I wish to raise one point in connection with part 2 of the paper by Evans and Sels in their discussion of parallel transmission lines. It sometimes happens that two transmission lines of different voltage are working in parallel and it is necessary to determine the line constants for the combined line. This may be done in the following manner. Use one voltage as a referenc voltage and determine the line constants, A_1, B_1, C_1 and D_1 of this line and also the line constants A_2, B_2, C_2 and D_2 of the other line. It is necessary now to transfer the second set of constants into new constants referred to the reference voltage. The A constant will remain the same, the B constant must be multiplied by the square of the ratio of the voltages, and the C constant must be multiplied by the reciprocal of that ratio squared, the D constant remaining the same. Equations **18** to **21** may then be applied.

The method of determining the division of load between the lines may be had by reference to Fig. 1 of the paper by C. L. Fortescue and S. C. F. Wagner, since whichever path is followed the voltage vector must turn through the same angle for equal voltage so that by plotting the circle diagram for both lines separately and for the combined lines we can determine the angle θ for any given load on the combined line and by drawing this same angle on the separate line diagram, determine the amount of load on each line.

TABLE I

Kv-a. in thousands required at salient points for various loads delivered. Case I.

Load	Kv-a.$_S$	Kv-a.$_R$	Total Kv-a.*net*
125	−24	+24	0
100	−48	−25	− 73
75	−63	−48	−111
50	−73	−64	−137
0	−78	−77	−155

TABLE II

Kv-a. in thousands required at salient points for various loads delivered. Case 2.

Load	Kv-a.$_R$	Kv-a.$_M$	Kv-a.$_S$	Total Kv-a.
188	+103	+250	+152	+505
150	+ 45	+ 61	+ 26	+132
100	+ 3	− 22	− 15	− 34
80	− 20	− 63	− 25	−108
0	− 30	− 75	− 30	−135

TABLE III

Kv-a. in thousands required at salient points for various loads delivered. Case 3.

Load	Kv-a.$_R$	Kv-a.$_{M2}$	Kv-a.$_{M1}$	Kv-a.$_S$	Total Kv-a.
200	+77	+106	+132	+61	+376
150	+35	+ 37	+ 41	+14	+127
100	+ 7	− 13	− 15	−12	− 33
50	−10	− 38	− 40	−20	−108
0	−20	− 45	− 48	−20	−133

TABLE IV.

Kv-a. in thousands required at salient points for various loads delivered. Case 4

Load	Kv-a.$_R$	Kv-a.$_{M3}$	Kv-a.$_{M2}$	Kv-a.$_{M1}$	Kv-a.$_S$	Totalkv-a.
250	+109	+147	+143	+225	+120	+744
200	+ 65	+ 72	+ 66	+101	+ 48	+352
150	+ 34	+ 20	+ 15	+ 32	+ 12	+113
100	+ 12	− 12	− 17	− 7	− 5	− 29
50	− 2	− 30	− 35	− 27	− 12	−106
0	− 11	− 35	− 40	− 34	− 10	−130

L. A. Herdt (by letter): I read with great interest the paper by Messrs. Fortescue and Wagner on "Some theoretical consideration of Power Transmission" in the February 1924 issue of the JOURNAL of the A. I. E. E.

I noted (and they are not the only writers that do so) that the term *Synchronous Condenser* is used—Leading and Lagging Condenser Fig. 2. Applied to such machines this term is a misnomer, giving the impression that the chief function of the machine is to supply leading current while this represents but one-half of its use in service. The other and fully as important function is to supply *lagging* current.

The use of the term *Synchronous Reactor* for such machines was suggested by the writer (see the *Electric Journal* September, 1915—Constant Voltage Operation of a High-Voltage Transmission System) in view of the common use of the term reactance as positive to represent inductive reactance and negative to represent condensive reactance.

A synchronous reactor is a machine having the property of reactance positive or negative, that is inductive or condensive.

A. E. Kennelly (by letter): The paper by Mr. Thomas is valuable in presenting the conditions that may be expected to occur during the steady-state, over a power-transmission line of unusual and hitherto unattained length, operated three phase at 220 kilovolts.

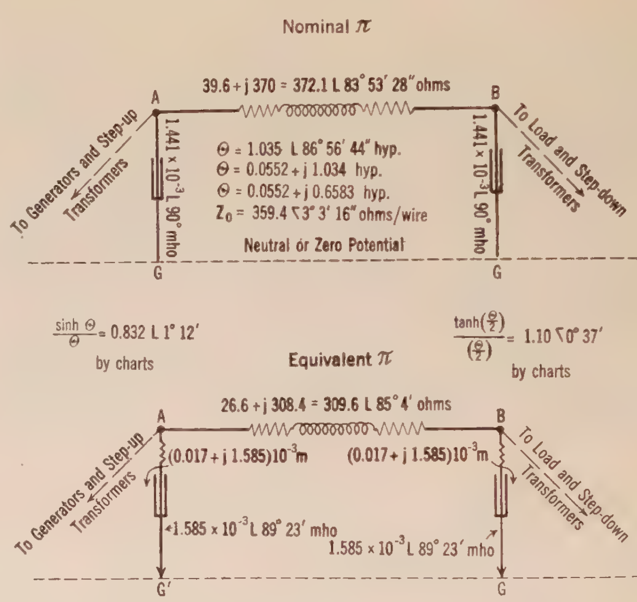

FIG. 46

Nominal and Equivalent π of one of the three-line conductors considered in the Thomas superpower transmission paper:

L = 804.7 km. = 500 mi. f = 60~ D = 15.8′ = 4.816m d = 0.0278 m.
r = 0.04921 ω/w. km. = 0.07920 ω/w. mile R = 39.6 ω/wire
l = 1.220 × 10^{-3} h/w. km = 1.963 × 10^{-3} h/w. mi; $j\,x$ = j 0.46 ω/w. km = j 0.74 ω/w. mi; $j\,x$ = j 370 ω/wire.
L = 0.9815 h/wire: g = 0 G = 0. c = 0.950 × 10^{-8} f/w. km. = 1.529 × 10^{-8} f/w. mi.
C = 7.645 × 10^{-6} f. $j\,b$ = 3.581 × 10^{-6} m/w. km. = j 5.763 × 10^{-5} n/w. mi. $j\,B$ = j 2.882 × 10^{-3} n/wire.

On three-phase power-transmission lines of the lengths that have hitherto come into service, the hyperbolic-formula corrections for the effects of distributed capacitance at the fundamental frequency of 60 cycles per second, have been small. In most cases, these corrections might be ignored in first-approximation calculations, and the lines treated on the basis of capacitance placed either in one lump at the middle of the line (for the nominal T), or in two equal lumps at the ends of the line (for the nominal π).

In the case, however, of Mr. Thomas' line, 500 miles long

(804.7 km), the nominal π of any one of the three line conductors has an appreciable error at 60 cycles per second, and has to be corrected by some process which takes the uniform distribution of capacitance into account. This is done in the paper by means of the equations at the foot of its third page, and which have been shown by Mr. Thomas in an earlier paper to be suitable for the purpose. An alternative method, preferred by the writer, is to form the equivalent[8] π of one line, such that the electrical behavior of this π, according to Ohm's Law, gives the same voltages, currents and powers at its terminals under the assigned conditions of load, as the actual line with its distributed constants.

In the accompanying Fig. 46, $A\ B\ G\ G$ represents the nominal π of one of the conductors considered in Mr. Thomas' interesting paper. The line has $R = 39.6$ ohms resistance in the conductor, and also $X = 370$ ohms reactance, at the working frequency of 60 cycles per second, assuming that there are no harmonics present in the voltage or in the current. The line leakance is ignored ($G = O$), and the total dielectric susceptance is taken as $j2.882$ millimhos, divided into two terminal condensers of $j1.441$ millimhos each.

The angle θ of the line is $\sqrt{Z\ Y} = 1.035 \angle 86°.56'\ .44''$ hyperbolic radians, and the correction factors, by reference to the charts prepared for that purpose,[9] are $0.832 \angle 1°.12'$ for the architrave of the π, and $1.10 \diagdown 0°.37'$ for each pillar. Applying these factors, we obtain the equivalent π, $A'\ B'\ G'\ G'$ in the lower part of the Fig. 46. The line behaves as though it had 27.0 ohms resistance instead of 39.6, a reduction of 31.8 per cent, and $j\ 312.4$ ohms reactance instead of $j\ 370$, a reduction of 15.5 per cent. The effect of distributed capacity upon the π of the line $A\ B\ G\ G$, is to reduce its apparent conductor resistance by nearly one third. The admittance of each pillar is, however, increased ten per cent, to 1.585 millimhos, with a small leak element added of 0.017 millimho. If now the load to neutral be attached at B' and the generator apparatus at A', the equivalent π enables the terminal voltages, currents and powers to be determined by the ordinary vector Ohm's law calculation.

It is evident that the hyperbolic correction factors for a line of this length operated at 60 cycles, are by no means negligible.

F. R. Sharpe: The mathematical results found by Fortescue and Wagner may be expressed in the following simple form.

(A) Consider the normals in Fig. 47 drawn at any point P of a parabola to meet the axis in N. A circle with its center at N and of radius $P\ N$ will touch the parabola at P and at the symmetrical point P'. The envelope of all such circles is clearly the parabola. The smallest circle has the radius $2\ p$ and is tangent to the parabola at its vertex V.

If we denote $F\ N$ by h the radius is

$$P\ N = \sqrt{P\ M^2 + M\ N^2} = \sqrt{4\ p\ V\ M + (2\ p)^2} = \sqrt{4\ p\ h}$$

Hence the envelope of the circles

$$(x - h)^2 + y^2 = 4\ p\ h \tag{1}$$

is the parabola $y^2 = 4\ p\ (x + p)$, the origin being the focus F.

In the case of the receiver circles the vectorial form of the equation (1) is

$$R = \frac{P_r + j\ Q\ v}{\alpha - j\ \beta} = E_r^2 - \frac{\gamma - j\ \delta}{\alpha - j\ \beta} E_s\ E_{re}{}^{-j\theta}$$

$$= E_r^2 - \sqrt{\frac{\gamma^2 + \delta^2}{\alpha^2 + \beta^2}}\ E_s\ E_{re}{}^{-j\theta'} \tag{2}$$

where $\theta' = \theta + \theta_1 - \theta_2$

so that $h = E_r^2$ and $4\ p = \dfrac{\gamma^2 + \delta^2}{\alpha^2 + \beta^2} E_s^2$

8. "Artificial Lines for Continuous Currents in the Steady State" A. E. Kennelly, *Am. Ac. of Arts & Sciences*, Vol. 44, No. 4, Aug. 1908, page 97.

9. "Electrical Characteristics of Transmission Lines" by Wm. Nesbit, Westinghouse El. & Mfg. Co., Publication, Pittsburgh, Feb. 1922.

(B) We may also derive the same results by vector differentiation of (2): The vector to a point of intersection Q of (2) with the neighboring circle is given by (2) and by

$$R = (E_r + \delta\ E_r)^2 - \sqrt{4\ p}\ (E_r + \delta\ E_r)\ e^{-j}\ (\theta' + \delta\ \theta')$$

and is therefore determined by the vector equation

$$\theta = 2\ E_r\ \delta\ E_r - \sqrt{4\ p}\ \delta\ E_r\ e^{-j\theta'} + \sqrt{4\ p}\ E_r\ e^{-j\theta'}\ j\ \delta\ \theta'$$

as in the case of ordinary differentiation. Hence taking the real and imaginary parts we have

$$(2\ E_r - \sqrt{4\ p} \cos\theta')\ \delta\ E_r - \sqrt{4\ p}\ E_r \sin\theta'\ \delta\ \theta' = 0$$

and

$$\sin\theta'\ \delta\ E_r - E_r \cos\theta'\ \delta\ \theta' = 0$$

Hence $$\frac{2\ E_r - \sqrt{4}\ p \cos\theta'}{\sin\theta'} = \frac{\sqrt{4}\ p \sin\theta'}{\cos\theta'}$$

that is

$$E_r \cos\theta' = \sqrt{p}$$

$$E_r = \sqrt{p} \sec.\ \theta' \tag{3}$$

Hence the envelope from (2) is

$$R = p \sec^2\theta' - 2\ p \sec\theta'\ e^{-j\theta'}$$

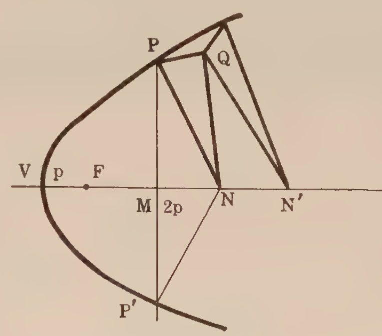

Fig. 47

$$= p \tan^2\theta' - p + 2\ p \tan\theta'\ j = x + j\ y$$

Hence $y = 2\ p \tan\theta'$; $x = p \tan^2\theta' - p$; or eliminating $\tan\theta'$, $y^2 = 4\ p\ (x + p)$.

(C) The differentiation performed graphically gives at once the result

$$\cos(\theta' + \delta\ \theta') = \frac{\sqrt{4\ p}\ \delta\ E_r}{2\ E_r\ \delta\ E_r} \text{ approximately}$$

because $$\cos Q\ N'\ N = \frac{Q\ N' - Q\ N}{N\ N'}$$

and taking the limit, as $\delta\ E_r$ and $\delta\ \theta'$ approach 0,

$$\cos\theta' = \frac{\sqrt{4\ p}}{2\ E_r} \text{ as in (3).}$$

F. W. Peek, Jr: All of these papers refer to a specific problem,—the transmission of a large amount of power 500 miles at 220 kilovolts, sixty cycles. It happens that a 500-mile line is not economical unless power of the order of 100,000 kw. per circuit can be delivered over it. This is a rather large amount of power for 500-mile transmission at 220 kv. under the conditions fixed by the problem. Since the load must be increased to the limit for economic reasons the question of stability is an important factor. A higher voltage or lower frequency would permit greater power per circuit without approaching the instability point. The difficulties, therefore, arise to a considerable extent from the fixed conditions of the problems rather than to limitations of high-voltage transmission.

It is not the actual physical length of the line that causes limitations. Limitations are caused by certain factors that depend upon physical length, mainly inductance, but to some extent capacity and resistance. If the inductance is reduced the line has the characteristics of one of short length. Some time ago Mr. Percy Thomas suggested how this might be done by "split conductors." Split conductors are also advantageous

from the corona standpoint. At 25 cycles this line would have characteristics similar to present 220-kv. lines 200 miles in length.

In considering the effects of transient load changes on stability it is not only necessary to consider how quickly the generator can respond but also what the increments of load are and how rapidly they can be changed. The size of the system is an important factor.

It is interesting that it is not necessary to discuss insulation limitations. As the transmission voltages and distances of transmission increase the size of apparatus units increases and becomes an important problem. This introduces the question of size of material and difficulties of transporting built-up units.

Chairman Baum: I have been working, as some of you know, with quite a large transmission system for the last twenty-five years. As I say, the stability of that system has been increasing all the time and the last addition of the synchronous condensers has increased the stability so markedly that if you talk to the operators, they will tell you right away how easy it is to operate and how difficult it is to shake that system apart.

I don't think the load transients should apply to your regulation, back to include your generator reactance.

I think Mr. Thomas is too pessimistic about his system, but the only criticism I would make is this: he thinks the switching is difficult. Therefore, he eliminates the high-tension switching. As a matter of fact, the high-tension switching has been of no trouble on our system, and is one of the most satisfactory thing we have. We laid down the rule twenty years ago that the highs tension switching must be the same as low-tension switching, and I don't believe you can have a successful transmission system without that condition being fulfilled.

If you put that condition down, that you must have switching in and out, no matter what the time of day or what the conditions are, then you must have that line cut up into sections, you can't help that, and that means of course adding some cost. People say the cost of condensers and the cost of switching is too great. When you get through, the cost per kilowatt transmitted is the real thing you are after, and the cost per kilowatt at two hundred twenty thousand is about one-half the cost per kilowatt at one hundred ten thousand and that is the real answer to your transmission problem.

(*To be continued*)

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

THE RELATIONSHIP OF THE SCIENTIST TO ILLUMINATING ENGINEERING

We often hear of "man's conquest of nature," but such a cataclysm as the Japanese earthquake shows such a phrase to be a mere idle boast. Man has learned to use a few of nature's forces, but when she rises in wrath, he scurries helplessly to such refuge as he can find. It is not only great disasters, such as earthquakes, volcanic eruptions, and floods, that drive him to cover, but, just as ancient man sought shelter in his cave or rude hut from storms and cold, even so must we today shield ourselves in our better built and better heated homes from the climatic severities we have no power to mitigate. It is idle to talk of conquest when, hidden in our dugouts, we cannot even give battle.

On only one section of the front have we gained ground, but there our drive has been successful and is still gaining momentum. Darkness, an enemy that brought helpless fear to ancient man, has lost its terrors. We have not only driven it from our homes, but are pushing it back on nature's own terrain, the great outdoors. Our streets, and gradually our highways, are being made safe for photocracy. Even on desolate country roads our motor headlights roll the enemy back before us at will. Artificial light is the one really successful weapon that has been developed for fighting nature on her own ground.

The attack began many decades ago, with the gas lamp, the arc light, and the carbon filament incandescent, but in the last twenty years the advance has been most swift. It has been a triumph for the combined forces of science and engineering. The new illuminants discovered by science have followed each other in rapid succession. The "metallized" filament, the first step toward higher efficiencies; the tungsten filament, bringing a still greater gain in efficiency; the magnetite arc, the only arc lamp to survive the competition from the modern incandescent; drawn tungsten, making the tungsten lamp economical in manufacture and sufficiently sturdy for use even on motor vehicles and battleships; and finally the gas-filled tungsten lamp, still more efficient and capable of production in large units (lamps of 30 kw. have been made). These developments, all coming within hardly more than ten years, have more than quadrupled the efficiency of lighting, so that, in the general great increase in living costs, light is the one important commodity costing far less than twenty years ago.

* * * * *

But engineering too has played an essential part in the advance. The new illuminants had first to be developed into reliable economical lamps of many types and sizes, and then the illuminating engineer had to develop the new technique for employing these lamps to best advantage. This development involved the study and solution of many important problems. For instance, in the filament of the gas-filled lamps, the illuminating engineer had to deal with a light source about ninety times as brilliant as a Welsbach mantle and more than six times brighter than the carbon filament. Glare for the first time became a really serious problem, and it is no wonder that mistakes were made in many initial installations of the new lamps. But the illuminating engineers are fast rectifying past mistakes and have gone far in establishing principles and standards for correct lighting in all its multifarious applications. They have caught up with the physicist and are ready for the next advance.

It is about a decade since the gas-filled lamp appeared on the market, but we cannot believe it marks the limit of progress. The efficiency of conversion of electric energy into light is still only a few per cent, and science will never be content to stop there. We believe that a new and more efficient light will some day come, and, when it does, the importance of the work of the illuminating engineer and his opportunity for achievement will be even greater than they are today.—Lawrence A. Hawkins, *Trans. I. E. S.*, Jan., 1924, p. 87.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

The Pasadena Convention and its Excellent Program

Many exceptional features of technical, social and scenic interest are offered to those who will attend the Fall Convention at Pasadena, October 13 to 17. The technical papers are of very high caliber and include such subjects as transmission and interconnection, utilization, machinery, electrophysics, telephony and street lighting. The transmission papers are of special importance as they represent some of the latest studies which have been made on high-voltage transmission. The papers on utilization are also valuable contributions and they cover the application of electrical power to such industries as lumber, mining, steel, irrigation, zinc smelting and electrometallurgy.

Dr. R. A. Millikan will give an address on some of his latest researches in electrophysics. This will be supplemented by a group of electrophysics papers delivered by members of the Norman Bridge Laboratory of the California Institute of Technology, of which laboratory Dr. Millikan is director.

A number of the noted pioneers of the Institute will give some reminiscences on their experiences in the electrical industry many years ago. This is an opportunity which will be highly appreciated by those attending.

Addresses by a number of prominent executives and engineers on Tuesday evening will be another feature of particular interest.

The entertainment and social events promise much enjoyment. A dinner dance is scheduled for Monday evening, a dinner at the California Institute of Technology on Wednesday evening, a pleasant entertainment on Thursday evening and a banquet on Friday evening.

Automobile trips will be made to some of the scenic attractions in the neighborhood, one enjoyable trip being that to Mt. Wilson where the famous observatory will be visited.

The capable body of men who compose the local convention committee assures a successful and enjoyable meeting. The committee is composed of the following: R. W. Sorensen, Chairman; O. F. Johnson, Secretary; J. E. MacDonald, Chairman of Program Committee; M. O. Bolser, E. E. F. Creighton, H. B. Dwight, E. R. Hannibal, C. R. Higson, W. C. Heston, C. W. Koiner J. A. Koontz C. A. Lund F. W. MacNeil, S. G. McMeen, L. W. W. Morrow, E. F. Pearson and E. R. Stauffacher.

FIG. 1—DEAD END TOWER ON 220-KV. LINE FROM EAGLE ROCK TO LAGUNA BELL, NEAR PASADENA

THE EXCURSION TRIP TO PASADENA

For the members from the eastern and middle sections of the country the excursion trip to the West will be an especially delightful feature. A number of the most prominent engineers and executives of the electrical industry together with the wives of many of them will make this trip in a body.

The route for the trip will be through Colorado Springs, Salt Lake City, Feather River Canyon, San Francisco, Yosemite and Los Angeles. It is probable that some special cars will be formed as far east as New York but the gathering point for the entire group will be Chicago.

FIG. 2—KERN RIVER NO. 3 POWER HOUSE. INSTALLED CAPACITY 32,000 KW.

The party will leave Chicago about the evening of September 26 and will travel via the Rock Island Railroad to Colorado Springs where one day and night (September 28) will be spent. Visits may be made to Pike's Peak, the Cave of the Winds, the Garden of the Gods, Manitou, and Cheyenne Canyon. On the 29th the party will view by daylight the scenery along the Denver and Rio Grande through the Rockies on the way to Salt Lake City. Arriving at Salt Lake City on the morning of September 30, there will be an opportunity for a drive along the mountain side overlooking the Great Salt Lake and a chance to visit the

great Morman temple and hear the mammoth organ at noon. Starting early in the afternoon of this day the train will pass through the Great Salt Lake and will proceed on the Western Pacific route through deserts of Nevada and through the Feather River Canyon in California on October 1, arriving in San Francisco in the evening.

Three days, October 2, 3 and 4, will be enjoyed in San Francisco and the neighborhood. The members of the party will be free to pass these days as they please, but for the convenience of those who care to attend, a number of trips will be scheduled. Probably trips will be taken on October 2 to the University of California, Berkeley and along the Rim Road. On October 3 trips may be made by railway to the top of Mount Tamalpais and down into the Muir Woods. On October 4 visits may be made to Golden Gate Park, the Cliff House, seal rocks, Golden Gate, Ocean Beach, the Presidio, Twin Peaks overlooking San Francisco, and Stanford University by the rim route overlooking San Francisco Bay on one side and the Pacific Ocean on the other.

The next four days will be spent in the Yosemite Valley. The party will travel from San Francisco to Merced on October 5. On the 6th the Hetch Hetchy Valley and its famous power station may be visited. On the 7th trips can be made to Mariposa to see the Big Trees and to Glacier Point, the best viewpoint of the Yosemite Valley and ridges of the Sierra Nevada Mountains. On the 8th the party will take in the views in the floor of the Yosemite.

Thus the party will arrive in Los Angeles on October 9 and here again four days may be enjoyed as desired. Among the

Fig. 3—Dam No. 6 on San Joaquin River at Intake of Big Creek No. 3, Corner of Big Creek No. 8 Power House and 220 Kv. Transmission Line showing in Background.

trips which may be taken on October 9 will be those to "Movie Town," the alligator farm and the ostrich farm. During the next two days, the 10th and 11th, a delightful trip by special automobiles will be arranged southward along the coast to San Diego and across the Mexican border into Tia Juana. Fatigue on this trip will be avoided by short stops at a number of places en route, such as the orange groves of Orange County, Long Beach, several old missions such as San Juan Capistrano, La Jolla Beach, Coronado Beach and Hotel, and several other points of minor interest. On the 12th a visit will be made to Catalina Island, giving a view of the marine gardens through the glass-bottomed boats and a sight of the only group of fur-seals south of the Behring Sea. This will bring the time up to the opening day of the Convention, October 13.

The return trip from Pasadena may be made by any of several different routes according to the wishes of the individuals. Naturally many will want to return by the route which touches the Grand Canyon of the Colorado. A one-day side trip as a minimum to the Canyon may be taken in connection with this route. There are altogether 14 days available after the convention for travel before the expiration of the summer excursion rates, midnight of October 31.

REDUCED RAILROAD FARES

As to the cost of the trip, rather complete information was given in the June issue of the Journal, page 572. A general

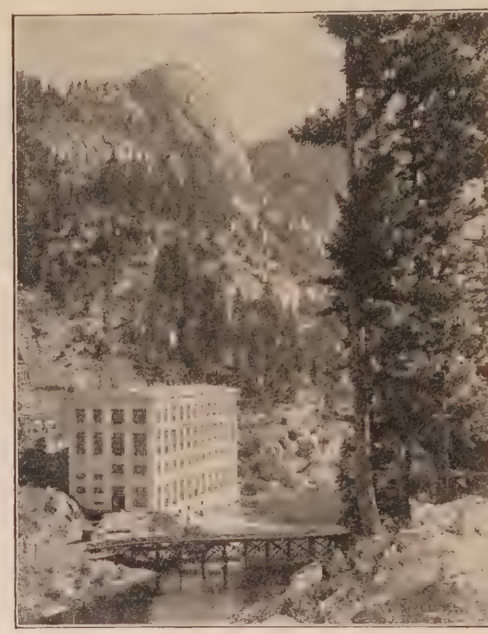

Fig. 4—Big Creek No. 1. Installed Capacity 48,000 Kw. Capacity after May, 1925—73,000 Kw.

estimate may be made if it is stated here that the round trip rate from New York to Los Angeles, including stopovers and a side trip to the Grand Canyon, will amount to about $225 including a lower berth. The rates from points other than New York, of course, are different in accordance with the distance.

All members who are interested in this excursion will confer a favor on the committee in charge if they will kindly send word to this effect to Institute Headquarters, New York. More details of this excursion to the greatest sights in the world are available, upon request, to anyone interested.

TENTATIVE PROGRAM OF THE FALL CONVENTION

Monday, October 13

Morning

Registration

Opening Session

President's Address, Farley Osgood

Transmission Session (dealing particularly with corona).

The Hysteresis Character of Corona Formation, Prof. H. J. Ryan and H. H. Henline, Stanford University.

A High-Voltage Wattmeter, Philip C. Clark and Chas. E. Miller, Stanford University.

Power Measurements at High Voltages and Low Power Factors, J. S. Carroll, T. F. Peterson and G. R. Stray, Stanford University.

Afternoon

Corona Losses from Large Cables, J. C. Clark, Stanford University and F. F. Evenson, Benson Lumber Co.

Corona-Loss Tests on 202-Mile, 220-kv. Transmission Line, Roy Wilkins, Pacific Gas & Electric Co.

Automobile Trips.

EVENING

Dinner.

Tuesday, October 14

MORNING

Transmission Session

The Corona as Lightning Arrester, John B. Whitehead, Johns Hopkins University.

Corona Losses between Wires at High Voltage, C. Francis Harding, Purdue University.

Lightning, E. E. F. Creighton, General Electric Company.

Lightning and Other Transients on Transmission Lines, F. W. Peek, Jr., General Electric Company.

AFTERNOON

Transmission and Interconnection Session

Transmission at 220 Kv. on Southern California Edison System (Composite paper by members of Southern California Edison Company)

Section 1. Description of System and Operating Experience, H. Michener.

Section 2. Protective System, E. R. Stauffacher.

Section 3. Economic Studies in Transmission-Line Design, W. D. Shaw and C. B. Carlson.

Section 4. Vibration of Conductors and Overhead Ground Wires, J. M. Gaylord.

Section 5. Location and Right-of-Way, V. D. Elliott.

Interconnection of Power Systems in the Southeastern States, W. E. Mitchell, Alabama Power Company.

EVENING

Addresses by prominent executives and engineers.

Wednesday, October 15

MORNING

Machinery and Transmission Session

Large Steam-Turbine Generators, W. J. Foster, E. H. Freiburghouse and M. A. Savage, General Electric Company.

Heating of Large Aluminum Transmission-Line Cables, R. J. C. Wood, Southern California Edison Co.

High-Voltage Line Insulation, A. O. Austin, Ohio Insulator Company.

A New Type of High-Tension Insulator, H. B. Smith, Worcester Polytechnic Institute.

AFTERNOON

Research and Electrophysics Session

(The eight papers following are by members of Norman Bridge Laboratory of Physics, California Institute of Technology.)

Influence of Temperature on Photo-Electric Emission, R. C. Burt.

Collisions of the Second Kind, Stanislaw Loria.

Electric Currents Due to Fields Alone, S. S. MacKeown.

Electronic Orbits in Atoms, R. A. Millikan and I. S. Bowen.

Transfer of Radiant Energy to Free Electrons, E. C. Watson.

Electronic Emission under the Bombardment of Positive Ions, A. L. Klein.

A Magnetic Lens, W. R. Smyth.

A Complex-Quantity Slide Rule, J. W. M. Du Mond.

A Method of Obtaining Steady High-Voltage D. C. from a Thermionic Rectifier without a Filter, F. W. Maxstadt, California Institute of Technology.

EVENING

Dinner at California Institute of Technology

Lecture by Dr. R. A. Milliken, Norman Bridge Laboratory of Physics

Thursday, October 16

MORNING AND AFTERNOON

Utilization Session

Electricity in the Lumber Industry, J. L. Wright, General Electric Company.

Electricity in Mines, F. L. Stone, General Electric Company.

Contribution of Electricity to the Steel Industry, K. A. Pauly, General Electric Company.

Electrical Applications to Irrigation Pumping, R. H. Gates, Southern California Edison Company.

Electrical Equipment of Consolidated Lining and Smelting Company's Zinc Plant, R. H. N. Lockyer, West Cootenay Power Company.

Electrometallurgical Applications, J. L. M. Yardley, Westinghouse Electric & Mfg. Co.

AFTERNOON

Trip to Mount Wilson

EVENING

Entertainment Program

Friday, October 17

MORNING

Telephony and Illumination Session

Street Lighting, A Municipal Problem, R. D. Whitney, Syracuse University and Syracuse Bureau of Gas & Electricity.

Guided and Radiated Energy in Wire Transmission, J. R. Carson, American Telephone and Telegraph Company.

Telephone Transmission Maintenance Practises, W. H. Harden, American Telephone & Telegraph Co.

Telephonic Line Balance, L. P. Ferris and R. G. McCurdy, American Telephone & Telegraph Co.

AFTERNOON

Golf and Tennis Tournaments and other sports

EVENING

Banquet.

Reminiscences by Institute Pioneers.

Saturday, October 18

Trips to Interesting Points

Address of President-Elect Osgood

ANNUAL CONVENTION, EDGEWATER BEACH, CHICAGO

Probably the happiest moment of my life was when President Ryan in New York a short time ago gave out the information that you had chosen me as the next President of the Institute. That the Presidency is a position of distinction and dignity, I fully realize. I understand thoroughly the traditions, and the conservatisms of our Institute, and I am not unmindful that the administration properly carried on means a lot of hard work. I hope to be able to carry the Institute on as you would like it done.

I think this is the time for the President-Elect to listen rather than talk, and if the result of yesterday's conference, which was really in advance of the actual Convention, is any indication, the President-Elect is going to hear a lot.

The electrical engineer is a useful member in the world's society. No other engineer has done more for the comforts, economics and physical accomplishments in the world. Yet we must not be unmindful that it takes all the other kinds of engineers with whom we work to bring about a complete success of things in hand.

You would be surprised to know how many thoughts have already been expressed to your President-Elect as to what should be done and what should not be done for the best interests of electrical engineering and our Institute, and I think the impression which I have gained by these expressed thoughts so far is that we must take care of all phases of our necessities.

The Institute is passing through one of the most important stages in its evolution. Fifteen years ago the Institute work was quite different from today's scheme of handling things, for with a membership now of over 16,000 spread out all over the world, we have to reach each and every one of our members in some helpful, practical and yet proper way.

The thought is that while many of our meetings have to be of a not too strictly theoretical and technical nature, however that

phase of our engineering must be carefully protected and outlets made for an expression of that part of our work.

On the other hand, the pure scientists, the fine mathematicians and the highly technical members of our Institute must not forget that important, of course, as is the technique of electrical engineering, it cannot be separated from the applied side of engineering with its natural human requirements.

The electrical engineer is an inquisitive sort of fellow, and that is one of the reasons why we have been able to make progress as fast as we have. It comes out in a number of ways. In talking with some of the fellows yesterday about the best type of meeting in order to get a good audience in our various Sections, the combination meeting with other engineering societies was spoken of, and it was brought out quite clearly that the majority of engineers at such meetings would be the electrical engineers, fewer mechanicals, fewer civils; the electricals would be there where the subject of the evening was strictly electrical engineering or one which might properly be sponsored by some of the other engineering societies. Maybe it is because we belong to a new school that we are so inquisitive, but that brings us progress. We are, however, not always right. Some time ago I was riding along with some of our engineers, and I think for the very first time we had one of these flashing traffic signs come up in front of us. It was in a place where its usefulness was splendid, and we all exclaimed, "Why, isn't that fine!"

I said, "How does it work?"

One of our engineers said, "It works this way." Another one in the car said, "No, I think it works so-and-so." One of the other fellows said, "I do not think you are right, I think it works this way." (That is just as we discuss our theories in conference.) The chauffeur, unable to stand all this line of talk further, said, "Gentlemen, it works with acetylene gas."

That is the spirit of the electrical engineer—always inquisitive.

Another thing that has brought our Institute so nicely forward is the friendliness of our discussions, the ability to put each phase of any problem into the center of the ring and tear it apart and still come out alive. You can get into the severest discussions, if you wish, and still not want to commit murder. Not long ago we were in a conference, and there was a very decided divergence of opinion on quite an important matter, and the two fellows discussing it were not getting very far toward the conclusion, yet each was arguing well.

One of the fellows said, "Of course, there are two sides to every question. There is your side and the right side." But it is that spirit that gets us forward, and I certainly am glad for it.

In the matter of the administration of the Institute's affairs, I can only offer myself to you as your representative at Headquarters, which I feel is my duty as well as my pleasure. You hear various sorts of suggestions as to why this or that is not done—"Why don't *they* do this? Why don't *they* do that?" Who are "*they*"? "They" is the Institute membership. Please do not forget that, and if you start to shooting something into the middle of the circle, it will come back to you fairly and squarely, just as when you throw a rock into the middle of a pond a ripple will be started which will come to the shore at your own feet. When you shoot, shoot fairly and know that your shot will be accepted in the spirit in which it is sent.

We have had considerable discussion, particularly yesterday, as to how we may best go forward with our Institute plans, and I only ask that the membership have patience in the realization that in an organization as large as this, with so many divergent interests, it takes time to accomplish the very thing which everybody wants and agrees we want.

So let us go forward, and let us demonstrate the thought, one for all, meaning in the person of your President-Elect for the entire membership of the Institute, and all for one, meaning the entire membership for the good, for the love, for the promotion of the Institute itself.

A. I. E. E. Directors' Meeting

The first meeting of the Board of Directors of the American Institute of Electrical Engineers for the administrative year beginning August 1, 1924, was held at Institute headquarters, New York, on Tuesday, August 12.

There were present: President Farley Osgood Newark, N. J.; Vice-Presidents William F. James, Philadelphia, Harold B. Smith, Worcester; Managers R. B. Williamson, Milwaukee, A. G. Pierce, Pittsburgh, Harlan A. Pratt, Hoboken, N. J., H. P. Charlesworth, New York, J. M. Bryant, Austin, Tex.; Treasurer George A. Hamilton, Elizabeth, N. J.; F. A. Norris, representing Secretary F. L. Hutchinson, New York.

The following resolution was adopted account of the recent death of John H. Dunlap, Secretary, American Society of Civil Engineers:

Whereas, the American Institute of Electrical Engineers has learned of the recent sad loss incurred by the American Society of Civil Engineers through the death of its Secretary, John H. Dunlap, be it

Resolved: That the Board of Directors of the Institute hereby expresses its deep regret and sorrow for the unfortunate occurrence which has removed from the ranks of the Engineering Societies one who was regarded with appreciation and respect.

Payment of monthly bills, amounting to $16,841.89, was approved.

A report was presented of a meeting of the Board of Examiners held July 31, 1924, and the actions taken at that meeting on applications for election and transfer were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 31 Students were ordered enrolled; 94 applicants were elected to the grade of Associate; 9 applicants were elected to the grade of Member; 4 applicants were transferred to the grade of Member.

President Osgood announced the appointment of committees for the administrative year beginning August 1, 1924. (A list of the committees is printed elsewhere in this issue.)

In accordance with the requirements of the by-laws of the Edison Medal Committee, the Board confirmed the following appointments by the President to the committee: Messrs. N. A. Carle, W. C. L. Eglin, and John W. Lieb, for the five-year term ending July 31, 1929; Mr. Samuel Insull to fill the unexpired term of H. M. Byllesby, deceased, ending July 31, 1925; Mr. Gano Dunn as chairman of the committee, to succeed Mr. Edward D. Adams, whose term as a member of the committee expired July 31, 1924.

Also conforming with the by-laws of the Edison Medal Committee, the Board of Directors elected the following from its own membership, for the two-year term ending July 31, 1926: Mr. L. F. Morehouse, Professor Harris J. Ryan, and Professor Harold B. Smith.

The following Local Honorary Secretaries of the Institute were reappointed by the Board, for the term of two years ending July 31, 1926: Messrs. Lawrence Birks, for New Zealand; W. Elsdon-Dew, for Transvaal; A. S. Garfield, for France; H. P. Gibbs, for India; and Carroll M. Mauseau, for Brazil.

A memorial resolution to the late Benjamin G. Lamme was adopted, as printed elsewhere in this issue.

The Board directed that publicity be given, through the pages of the Journal, to a communication received from the Societe Francaise des Electriciens, inviting the members of the A. I. E. E. to present discussions of subjects to be considered at a meeting of the French society to be held in Paris, December 26-31, 1924.

Various recommendations of the delegates of the Sections in conference during the Annual Convention, in June, were presented and acted upon as follows:

That consideration be given to adopting as accepted Institute practise the holding of District or regional meetings, and that a study be made by a special committee of the possibilities of such meetings and their development and relation to established conventions. The Board referred this to the Meetings and Papers

Committee for a statement as to the effect of the suggested policy on the plans of that committee, for recommendation regarding procedure, and for recommendation as to the desirability of appointing a special committee to study the subject.

That there be instituted a first-paper prize and a best-paper prize in each District, of $25 each, and offered by the national body of the Institute. It was voted to refer this to the Finance Committee for recommendation.

That expenses be paid from the national treasury for one visit each year by the Vice-President of each District to every Section in the District. The Board voted to refer this to the Finance Committee for recommendation.

That an appropriation be made to cover the expenses of two delegates from each Section, namely, the outgoing and the incoming chairmen, to the annual Section Delegates' Conference, instead of one delegate per Section as now authorized. Referred to the Finance Committee for recommendation.

The Board approved the recommendations of the Meetings and Papers Committee to the effect that the Midwinter Convention be held in New York, February 9-12, 1925; and that the Spring Convention of 1925 be held at St. Louis.

Announcement was made of a bequest by the late Benjamin G. Lamme, of $6000 to cover the annual award by the Institute of a gold medal, to a member of the Institute who has shown meritorious achievement in the development of electrical apparatus or machinery, the details of which will be arranged later by the officers of the Institute and the executors of Mr. Lamme's estate.

Due to the fact that the usual date of the October Board meeting would conflict with the Pacific Coast Convention of the Institute, Pasadena, October 13-17, the Board voted to hold the next Board meeting on Friday, September 26.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

Benjamin G. Lamme

The following memorial resolution to Mr. Lamme, who died July 8, was adopted by the Board of Directors of the American Institute of Electrical Engineers, at its meeting held August 12, 1924:

WHEREAS: Through the death of Benjamin G. Lamme there has been removed from the profession of Electrical Engineering one of its foremost representatives, who, by his assiduous exercise of the great talents entrusted to him, has been an outstanding factor in its accomplishment and advancement; and from the American Institute of Electrical Engineers one of its leading members whose character and personality have endeared him to all with whom he came in contact, and

WHEREAS: The Board of Directors of the American Institute of Electrical Engineers is fully sensible of the great loss which has been sustained both by the Profession and the Institute, be it

RESOLVED: That the Board, speaking for the entire membership, herewith registers its deep regret, and extends its sincere sympathy to those whose personal loss is infinitely greater than its own, and

RESOLVED: That in token of this action by the Institute a copy hereof be spread upon its minutes and published in its JOURNAL.

French Society Invites Discussion on Technical Reports

Members of the Institute have been invited to contribute discussion on a number of reports which will be read at the meeting of the Societe Francaise des Electriciens to be held December 26 to 31, Paris, France. These reports will be sent to anyone who cares to read them at a cost of three francs each, plus postage. Requests should be sent directly to the following address: Societe Francaise des Electriciens, 14 Rue de Stael, Paris, France.

The discussions when prepared may be sent to A. I. E. E. headquarters, New York, as the Board of Directors of the Institute would prefer to send all discussions in a group as a contribution of the Institute. This discusion should be sent in promptly as the Societe wishes to complete its arrangements in October.

The topics covered in the reports, which are written in French, are as follows:

1, Coefficient of deformation of the curves of alternators; 2, Experiments on transformers with waves of high frequency or steep front; 3, Interconnection of networks; 4, Short circuits in alternators; 5, Study of insulation in machines.

6, Photometric units; 7, Colored photography; 8, Lighting in factories and schools; 9, Automobile headlights; 10, Lighting of public roadways at Paris; 11, The primary standard of luminous intensity.

12, Characteristic curves of electrolytic heaters; 13, Electric primary batteries; 14, The electrochemical industry in the Pyrenees; 15, The industry of electric storage batteries; 16, Thermic balance of electric heaters.

17, Substitution of iron for copper in traction lines; 18, Calculation of high-tension lines by the use of charts; 19, Dielectric losses in underground cables.

20, Modulation in wireless telephony; 21, Automatic telephony; 22, Radiocompass determination of the position of a metallic ship.

23, The industrial measurement of dielectric loss in insulated cables; 24, Apparatus for the study of the magnetic properties of sheet iron; 25, Study of discharges in gas; 26, Overload relays and differential protection; 27, Measurement of reactive energy.

Meeting of the Institute of Radio Engineers

The first meeting of The Institute of Radio Engineers for the winter season 1924-25 will be held on the evening of Wednesday, October 1, 1924, at 8:15 o'clock, in the Engineering Societies Building, 29 West 39th Street, New York City.

A paper on "Radio Direction Finding" by H. deA. Donisthorpe of the Marconi International Marine Communication Company, Ltd., will be presented. This important aid to navigation will be discussed from the practical point of view. All members of the Institute and their friends are cordially invited to attend.

AMERICAN CHEMICAL SOCIETY

FALL MEETING, SEPTEMBER 8-13

At the fall meeting of the A. C. S., to be held at Cornell University, Sept. 8-13, the chief topic for discussion will be the conservation of the nation's fuel supply.

Prof. S. W. Parr of the University of Illinois will lead round-table conferences on "The Storage of Coal and Spontaneous Combustion." The report of the Coal Storage Committee of the American Engineering Council and the plans of Secretary Hoover for the relief of coal shortage will also be discussed.

Many papers by leading chemists both here and abroad will be presented. Among the foreign visitors who will participate in the meeting are Sir Robert Robertson, president of the Faraday Society; Sir Max Muspratt, one of the leading industrial chemists of Great Britain; and Prof. S. P. L. Sorensen of Copenhagen, a leader of the academic school, and internationally known for his work on the hydrogen-ion, of which he is the discoverer.

Announcement of Chemical Exposition Date

As numerous inquiries have been received by the International Exposition Company, under whose management the Exposition of Chemical Industries has been held, in regard to holding the Exposition this year, an announcement has been sent out to the effect that no exposition will be held in 1924. At the 1923 meet-

ing, it was decided to hold all future exhibitions in New York and the date of the next meeting was set for Sept. 28 to Oct. 3, 1925. No exposition was scheduled for 1924. As the Chemical Exposition has been held without interruption since 1915, this evidently accounts for the confusion of dates.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Mamerdo Bauer C., Braden Copper Co., Rancagua, Chile, S. A.

2.—H. E. Bradley, 1 Pine Crest Drive, Hastings-on-Hudson, N. Y.

3.—John D. Brown, Celite Products Co., Box 639, Lompoc, Calif.

4.—Miguel Mesa Gutierrez, Bermardo Lopez 8, Jaen, Spain.

5.—W. T. Hutton, 6753 South Bishop St., Chicago, Ill.

6.—Erle M. Jones, 370 Pape Ave., Toronto, Ont., Can.

7.—Albert H. Lindley, 2616 Kate Ave., Baltimore, Md.

8.—Keith C. Millikin, Box 524, Midland, Ont., Can.

9.—Fred H. Nash, Box 366, Cushing, Okla.

10.—B. A. Ross, Phoenix Utility Co., Hazleton, Pa.

11.—Kenneth H. Sloan, 11 Spruce Road, Inwood, L. I., N. Y.

12.—John D. Suttor, Jr., Mazda House, Wentworth Ave., Sydney, N. S. W., Australia.

13.—George T. Tavenner, Kern House, 2nd Floor, 36-38 Kingsway, London, W. C. 2, England.

14.—J. L. Twining, Apt. 32, 703 9th Ave., Seattle, Wash.

15.—Hideo Yamada, 2 Nagasumi-cho, Asakusaku, Tokyo, Japan.

16.—Adolph L. Ziegler, Westinghouse E. & M. Co., 160 7th Ave., Brooklyn, N. Y.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES JULY 1-31, 1924

Unless otherwise specified, books in this list have been presented by the publishers. The society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ARC WELDING HANDBOOK.

By C. J. Holslag. N. Y., McGraw-Hill Book Co., 1924. 250 pp., illus., 8 x 5 in., fabrikoid. $2.00.

A simple, practical manual, which explains the methods step by step, so that the beginner may understand the equipment and the processes. The book is intended for welders and students in trade schools, and also as a guide to engineers and designers in the use of arc welding.

CHEMISTRY IN THE TWENTIETH CENTURY.

By E. F. Armstrong, Editor. N. Y., Macmillan Company, 1924. 281 pp., illus., diagrs., 10 x 7 in., cloth. $5.25.

Contents:—Introduction.—Role of chemistry in physical science.—Structure of the atom.—Crystallography.—Ray-analysis of crystals.—Rare gases of the atmosphere.—Chemistry of carbon compounds.—Milestones in organic chemistry.—Chemistry of colloids.—Catalysis.—Fats and oils.—Sugars and carbohydrates.—Cellulose.—Colour in nature.—Coal-tar colours.—Syntheses in the terpene series.—Alkaloids.—Nitrogenous constituents of the living cell.—Biochemistry and fermentation.—Chemistry in agriculture.—Alloys.—Pottery and refractories.—Flame, fuel and explosion.—Explosives.—Chemistry of photography.

The object of this volume is to put on record our knowledge of physical and chemical science with particular reference to the progress during the last thirty years, and to emphasize the part of British inquirers in that progress. It is designed for reading by all who have received or are receiving a training in science.

The various chapters are by scientists of eminence in the subjects upon which they write. The first few articles indicate the development of modern theories and give a clear picture of the position today and of the directions in which progress is to be anticipated. The other chapters are more specialized. They describe the actual progress in selected fields.

CRAIN'S MARKET DATA BOOK AND DIRECTORY OF CLASS, TRADE AND TECHNICAL PUBLICATIONS.

Fourth edition, 1924. Chicago, G. D. Crain, Jr., 1924. 505 pp., 9 x 6 in., cloth. $5.00.

This book is intended to furnish the salient data on production and consumption in the more important American industries and to provide a classified directory of class and technical periodicals, with complete information about circulation, advertising rates, etc. It will enable the manufacturer to ascertain readily the market probabilities in many lines and to select the most suitable journals in which to advertise his products.

HANDBUCH DES WASSERBAUES.

By Hubert Engels. 3rd edition. Leipzig, Wilhelm Engelmann, 1923. 2 v., illus., diagrs., tables, 10 x 7 in., cloth. 61 schw. fr.

These two large volumes present an interesting attempt to cover the entire subject of hydraulic engineering in a unified way, with proper proportion for each division of the subject. Two editions were exhausted in less than eight years, showing that the book has found a place.

The general plan and style of the book is similar to the well-known Handbuch den Ingenieurwissenschaften. The text is copiously illustrated with clear drawings and each subject is provided with a good list of references.

The book is divided into ten main divisions: The Occurrence and Movement of Waters; Hydrology; River Works; Dams; Protection of Land; Agricultural Hydraulic Works; Navigation Works; Ship Locks; Canalization of Streams and Ship Canals; Harbors.

Die Rationalisierung im Deutschen Werkzeugmaschinenbau.

By Fritz Wegelben. Berlin, Julius Springer, 1923. 172 pp., 10 x 6 in., paper. 1.45

This work is a presentation of "American" methods of organization and management, illustrated by the practise of the Ludwig Loewe Company, the first firm to adopt them in Germany. The book discusses the trend of development in industrial organization, standardization, specialization, methods of increasing productivity, personnel management, welfare work, wage systems, etc. The author writes from long experience as a factory manager and as a student of economics; he attempts to select essentials from the great diversity of problems connected with the rationalizing of industry and to present these with an appreciation of their economic significance.

Shop Mechanics, Pt. 1; Shop Arithmetic.

By Earle B. Norris & K. G. Smith. 2d edition. N. Y., McGraw-Hill Book Co., 1924. (Industrial education series). 257 pp., diagrs., tables, 9 x 6 in., cloth.

A textbook for shop men, which presents the fundamental principles of mathematics, using familiar terms and processes and gives applications to shop problems that arise in the metal working trades. Is well adapted for self-instruction.

Traite de Stabilité du Matériel des Chemins de Fer.

By Georges Marié. Paris et Liége, Ch. Béranger, 1924. 579 pp., diagrs., 11 x 7 in., cloth. (Gift of Author.)

The author of this work has long been a student of the question of the oscillations of steam and electric rolling stock at high speeds and has published a number of papers on phases of the problem during the past twenty years, for which he has been awarded prizes by the Institut de France and the Société des Ingenieurs Civils de France. In the present book the substance of these memoirs is included with other material in an extended study of the influence of the various elements of the track on train stability. The author analyzes the factors that control safe speed and shows how speeds may be increased by more careful design of roadway and rolling stock.

Principles of Railway Transportation.

By Eliot Jones. N. Y., Macmillan Co., 1924. 607 pp., 9 x 6 in., cloth. $3.50.

Contents:—Pt. 1, Introduction.—Pt. 2, Rates and rate making.—Pt. 3, Legislation to the entrance of the United States into the World War, April 1917.—Pt. 4, Some railroad problems.—Pt. 5, Railroads and the war.—Pt. 6, Railroads and reconstruction.

Designed primarily as a text for elementary courses, this book aims to set forth the essentials of the railroad problem with clearness, accuracy and impartiality. General readers will also find it useful as a statement of the essential background of the railroad problem, which will aid him to obtain an unbiased understanding of the fundamentals of the situation.

Theory and Application of Colloidal Behavior.

By Robert H. Bouge, Editor. N. Y., McGraw-Hill Book Co., 1924. 2 v., diagrs., tables, 8 x 5 in., cloth. $8.00.

This book is an attempt to meet the need for a comprehensive treatise on the chemistry of colloids, which will present both the theoretical and practical information available on the subject. It is the joint work of thirty-five eminent specialists in America, England and Germany. Every important theoretical aspect is considered, and many of the more conspicuous of the direct applications that have been made in geology, metallurgy, agriculture, medicine and manfuacturing are described. Numerous lists of references are given. The work will prove very useful for reference to all those concerned with colloidal behavior in science or in industry.

THE STORY OF BAKELITE

"The Story of Bakelite," by John Kimberly Mumford, is a most interesting little volume which has recently been published by the Robert L. Stillson Co., New York. It is not a text book, but the story of this modern miracle of science from the time when the world first began, through the various stages of experiment, to its present day use in the radio, automotive and other industries. The price is $1.00 per copy.

PERSONAL MENTION

S. A. Redding, formerly electrical engineer, Rio de Janeiro, Brazil, S. A., is now District Manager of the Packard Electric Co., 624-5 Healey Bldg., Atlanta, Ga.

John Allan has resigned his position with the Cia. Cubana de Electricidad, Santa Clara, Cuba, and is now manager of the Planta Electrica, Inc., San Pedro Sula, Honduras, C. A.

John M. Fernald, is now Branch Manager of the Cutler Hammer Mfg. Co., 52 Chauncy St., Boston, Mass., having left the employ of the S. A. Woods Machine Co. of that city.

H. L. Woolfenden, formerly associated with the Allis-Chalmers Mfg. Co., Denver, Col., has joined the Scott Valve Mfg. Co. of Detroit, Mich. and will have charge of Sales Promotion.

J. G. Hirsch has accepted a position as Asst. Mech. Supt. of the St. Joseph Lead Co., P. O. Box 690, Bonne Terre, Mo., having left the employ of the Benham Engineering Co., Kansas City, Mo.

James H. Miller, until recently employed as Inspector for McClellan & Junkersfeld, Inc., is now in the engineering department of the Public Service Production Company, 54 Park Place, Newark, N. J.

T. C. Thompson has become associated with the Bell Telephone Company of Canada, Montreal, Que., having resigned his position as Assistant Mechanical Engineer of the Crosby Steam Gage and Valve Co.

James R. Johnson has accepted the position of Superintendent in charge of plant, water supply lines and outgoing high-tension lines with the El Dorado Hydro Electric Plant, Western States Gas & Electric Co., Placerville, Cal.

John U. Heuser, who has been Branch Manager at Chicago for the Cutler Hammer Mfg. Co., has removed to Milwaukee where he will have charge of a new branch office, which will handle the sales in the northwestern territory.

F. E. Galbraith has resigned his position as Division Supt. of Line Construction of the American Telephone & Telegraph Co., Philadelphia, Pa., and is now with the General Motors Truck Company, 845 11th Avenue, New York City.

George Byron Coleman is now engaged in the development of inventions in transmission mechanism, coupling and brake; and is at present located in San Francisco, Cal., P. O. Box 2721. Mr. Coleman was formerly at 2243 Steiner St. of the same city.

George H. Wirth is now employed by the Edw. G. Budd Mfg. Co. as operator in charge of high-voltage substations, Philadelphia, Pa. Mr. Wirth, previous to this, had been electrical engineer with the Right and Left Tool Holder Co. of Philadelphia.

Professor Michael I. Pupin and Dean George B. Pegram of the Schools of Mines, Engineering and Chemistry, have been designated by President Nicholas Murray Butler to represent Columbia University at the centenary of the Franklin Institute, Philadelphia, September 17-19.

Obituary

Fenwick J. T. Stewart, former president of the National Fire Protection Assn., died on August 6, 1924. Mr. Stewart was born in Washington, D. C. December 17, 1869. He received his A. B. degree from Georgetown University in 1891 and two years later was presented with the M. E. degree by Cornell University. Most of Mr. Stewart's energies were directed toward the enforcement of rules in connection with electrical fire protection devices.

Since the year 1909 he had held the position of Supt., Bureau of Surveys and Electricity, N. Y. Board of Fire Underwriters, during which time he was also a member of a Committee of Engineers directing test work of the Underwriters Laboratories, Chicago, Ill. Mr. Stewart became a Member of the Institute in 1917.

Henry Hopkins Lyon, electrical engineer with the Buffalo General Electric Co., fatally shot his wife and two small sons, afterward killing himself, on August 7, 1924. A note which he left for his sister gave no reason for the tragedy.

Mr. Lyon was a graduate of Cornell University and has been connected with the Wagner Elec. & Mfg. Co., St. Louis, Mo.; the General Electric Co., Schenectady, N. Y. and the Cataract Power & Conduit Co., Buffalo, N. Y. He has been an Associate of the Institute since 1905.

Foster Veitenheimer, an Associate of the Institute, died on July 24, 1924 at the Emergency Hospital, Washington, D. C., after an illness of several months.

Lieut. Col. Veitenheimer had been connected with the U. S. War Dept. since about 1900, serving in the Washington Navy yard and in various stations in the United States. During the war he was assistant engineer in the signal corps and later was made lieutenant colonel in the officers' reserve corps. A little over a year ago he returned to the United States from Hawaii, where he had been installing power plants in military post fortifications. At the time of his death Col. Veitenheimer was connected with the office of Chief of Engineers, War Dept., Washington, D. C.

Frederick A. Hall, assistant designing engineer of the Generator Section, Turbine Department of the General Electric Company at Lynn, Mass., died at Contoocook, N. H., August 12th. He had been in poor health since the beginning of the year, but his death came suddenly from heart failure. He was born in Christiania, Norway, in May 1865 and came to the United States about 1890. He was employed with the Thomson Electric Welding Company, the Thomson-Houston Electric Company and the General Electric Company at Lynn. From 1894 to 1897 he was an assistant on direct current generator design at the Schenectady Works under H. F. T. Erben; he was associated with various electrical organizations including the Westinghouse Electric & Mfg. Co., the Crocker Wheeler Co., Ingersoll-Rand Company, and H. F. Parshall, from 1897 until 1907 when he returned to the General Electric Company, Turbine Department, West Lynn, to the position which he has held since, mostly as a designer of turbine alternators.

Mr. Hall was also a cellist of rare merit and his artistry gathered about him a host of friends.

He became an Associate of the Institute in 1899 and a Member in 1913.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will, it is hoped, be sufficient, not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

CIRCUIT BREAKER ENGINEER. Must have had good technical schooling and considerable experience in designing air braker breakers of all capacities. Preferably experienced also in moderate voltage oil breaker design. Apply by letter only, giving record in detail and stating salary desired. Location, Pennsylvania. R-4500 Roller Smith Co., Bethlehem, Pennsylvania.

GAS ENGINEER, technical graduate, operating construction and design experience in water gas plants of ten million cubic feet capacity. Must be capable of supervising design and conconstruction. Salary minimum $8000 a year. R-4459.

METER ENGINEER, college graudate preferred with at least four years' experience in connection with meter department routine. Must be qualified to supervise tests, inspections and wiring checks of watt-hour meters and maximum demand equipment on high tension installations. Alternating current theory essential. State salary desired and when available. Send photograph and copy of references. Location, New York City. R-4134.

TECHNICAL GRADUATE, young, with 2-4 years' electrical testing experience. Must be familiar with theory of A. C. and D. C. machines, for development and experimental work with manufacturing company. Oscillograph experience desirable, but not absolutely essential, Salary $2000-$2400 a year. Location, New York, R-3811.

MEN AVAILABLE

ELECTRICAL ENGINEER wants permanant connection. B. S. in E. E. 1917. Two years G. E. test, two years supply salesman, two years as an assistant to chief engineer of large hydro-electric company. Capable of performing duties of electrical engineer, sales engineer, or superintendent meter department. B-8427.

HARVARD GRADUATE (1920), ingenious and inventive, well grounded in mathematical physics and electrical theory, with four years' experience in the research laboratory of the Western Electric Company, desires work in laboratory, or experimental shop. Will not take a job that involves nothing but taking measurements. B-8390.

EXPERIMENTAL ENGINEER, graduate Electrical Engineer. Two years instructor M. E., two years combustion engineering, two years power sales, desires change where his wide experience can be put to use. Prefer instructorship in

M. E. or power sales with public utility company, middle Atlantic states. B-2783.

HYDRO-ELECTRIC ENGINEER, reconnaissance, surveys, designs, supervising construction, management. Experience in Spanish American countries and in United States. First class references in New York and elsewhere. Member A. I. E. E. B-6316.

YOUNG MAN, age 22, at present employed by an electric utility as inspector, would like to start with some electrical or scientific firm in New York, Has had two years as assistant in laboratory. Chance of advancement main reason of change. B-8442.

MECHANICAL AND ELECTRICAL ENGINEER with executive and sales training, age 42. Successful as power and maintenance engineer conversant with transmission and distribution of electrical energy; industrial plant layout. Now in semi managerial position. Prefer location adjacent to New York City. B-8448.

ENGINEERING GRADUATE R. E., American and German training, desires connection with concern offering opportunity to do traveling sales or other work in Germany. Enrolled modern salesmanship course. 26 years old. B-8447.

ELECTRICAL ENGINEERING GRADUATE of 1924, U. of Michigan, age 23, desires to start his practical experience with a reliable company. B-8472.

GRADUATE ELECTRICAL ENGINEER, two years student course with large eastern Massachusetts power and light company, one year distribution work with same company. Desires position in electrical engineering department of power and light company in distribution or station work. B-8279.

ELECTRICAL AND MECHANICAL ENGINEER, wide experience in installation, operation and rehabilitation of industrial plants seeks connection with industrial enterprise with a view to managing electrical and mechanical department as chief engineer, chief electrical or master mechanic. Would consider financial interest to the extent of $10,000 to $25,000 with company that can stand close investigation. B-8327.

RADIO ENGINEER, 24, unmarried; graduate electrical engineer eastern college, special training in radio. Manager radio department wholesale and retail electrical store two years. Experienced design, manufacture receiving and broadcast transmitting equipment. Commercial operators license: experienced announcer and program director. Particularly fitted to act as sales engineer for manufacturer of transmitting or better class receiving equipment. B-8476.

ELECTRICAL, LICENSED PROFESSIONAL ENGINEER, ten years appraisal and valuation experience in telephone, telegraph, electric light and power. Will consider a position in any part of the United States. B-8489.

ELECTRICAL AND VALUATION ENGINEER, technical graduate, N. Y. State license, 32, married. Ten years' experience public utility, engineering and construction. Valuation and rate engineer for large utility at present, familiar with classification of accounts, and would welcome chance to start such a department in some utility. B-8488.

ELECTRICAL ENGINEER, graduate June 1921. Three years' experience with public utility. At present employed but desires position with greater responsibility and better future. Will go any place in South including Mexico; available immediately. B-8490.

CORNELL GRADUATE AND MASTER'S DEGREE, ten years' experience hydro-electric and combustion, construction, operation, management. Last four years in Cuba. Available now. Member both A. I. E. E. and A. S. M. E. A-3494.

ELECTRICAL ENGINEER, technical graduate, wishes to connect with a live engineering organization. Twelve years wide experience in electrical design, office and field, of power stations substations, industrial buildings, with the largest engineering company. Have had responsible charge in field of appraisal of electrical properties. Associate A. I. E. E., N. E. L. A., holds state license. B-5393.

ENERGETIC YOUNG MAN, 31, sixteen years of electrical experience of various kinds. as apprentice, mechanic, engineering assistant and supervisor, desires to connect with a firm that provides equal opportunities for the college graduate and self educated practical man. B-8502.

POSITION OF RESPONSIBILITY desired by graduate electrical engineer, 35, with engineering firm, utility, or as representative of nontechnical institution. Broad engineering and business experience as executive; includes determination of designs for power plants, lines, factories, etc., selection of materials and equipment. Construction, supervision, investigations of rates, development and financing. B-8237.

ELECTRICAL ENGINEER, 1924 graduate, experienced in power measuring and metering for Stone & Webster Company. Excellent references. Available immediately. B-8510.

MEMBER Am. Soc. of C. E., and Am. Inst. of E. E., with extensive experience in this and foreign countries in executive capacities for large corporations, and in investigating and reporting on public utilities and waterpower, is available for home or foreign engagement. Clean and unbroken record to date. B-8480.

E. E. graduate M. I. T., 1924, age 21, desires a position in the electrical industry with opportunity for experience and advancement. Has had varied experience during vacations. Willing to work and prove his ability. B-8503.

ELECTRICAL ENGINEER, technical graduate, age, 33, married. Eight years on engineering design and construction of substations and power plants, with largest industrial and public utility corporations. Have had special training and success in relay protective schemes. Available thirty days after agreement. B-8505.

LATIN AMERICA, young E. E., Irishman, 27, single, in perfect health, with seven years' experience. Design and construction of Diesel, hydro and steam-electric stations, substations, transmission lines, distribution systems and industrial installations. At present electrical engineer to an oil company. Desires progressive position in Central or South America. B-8506.

ELECTRICAL ENGINEER, technical education, age 27, married. Four years in charge electrical designing, engineering and testing of therapeutic equipment. Experience includes designing rheostats, relays, solenoids and transformers. Desires change to responsible position in another field offering opportunity for advancement. Available on thirty days' notice. B-8057.

ELECTRICAL ENGINEER, age 30, technical graduate. Twelve years' experience on light, power and signal construction, maintenance, inspection, investigating, consulting and sales engineering, teaching electrical subjects and publication work. Desires change with future for executive work. At present employed. Available on 15 to 30 days' notice. B-247.

GRADUATE ELECTRICAL ENGINEER December 1923, age 24, single, Associate A. I. E. E. Desires position where chances for promotion are good. Western states preferred as location, but will go anywhere. B-8511.

ELECTRICAL MAINTENANCE AND CONSTRUCTION FOREMAN. Fully experienced on industrial power and lightning systems, also in the operation of substations and switchboards. Present position five years with large textile machine manufacturing company. Technical education, age 27, married. Would consider large industrial plant or public service company in New England states. B-8514.

CONSULTING AND CHIEF ENGINEER, age 39, having broad experience in design, construction and operation of generating, substations and industrial plants, transmission and distribution systems, radio stations and electrolysis surveys, desires a permanent position with reliable concern where the value of his services and unquestionable record will be appreciated. B-3954.

RECENT GRADUATE, B. S. in E. E. from M. I. T., 1924, age 21. Would like position where good experience and a change for advancement is offered. Positions in electrical testing, research or sales preferred. Permanent connection with good company is desired. Location dependant on opportunity offered. B-8516.

PLANT EQUIPMENT ENGINEER, technical graduate, fourteen years' experience in several branches of electrical and mechanical engineering mostly power house and industrial plant equipment, desires suitable connection with industrial plant or consulting engineer. Available on fifteen days' notice. B-6275.

ELECTRICAL ENGINEER-EXECUTIVE, twenty years' experience in design, construction and operation of hydro-electric plants, large size, and transmission lines up to 110,000 volt. Also industrial plant and electric furnace experience. New York State professional engineer license, Member A. I. E. E. B-6891.

TECHNICAL GRADUATE in E. E. Three years electrical experience in power switchboard installation. Good references, willing to work. Location preferred, New York City or suburbs or Jersey City. B-8526.

TECHNICAL GRADUATE, age 24, single, desires position as student engineer with large manufacturing concern to gain practical experience, with wages sufficient to live comfortably. Student of I. E. E. (London) and A. I. E. E. Holds first class city and Guilds Certificate in electrical engineering. Location preferred, Schenectady or Pittsburgh. B-8637.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED AUGUST 12, 1924

*AHMED, SYED HABIBUDDIN, Operating Dept., Commonwealth Edison Co., 72 W. W. Adams St., Chicago, Ill.

ALLEN, EUGENE BELL, Electrical Inspector, Allen Engineering Co., Hamilton, Ont., Can.

*BOSSHARDT, WILLMERT CLARENCE, Credit Manager, Fosston Mfg. Co., St. Paul, Minn.

BOUMEESTER, HUIBERT GERARD, 230 West 99th St., New York, N. Y.

*BRICKS, HARRY MAXWELL, Industrial Control Engg. Dept., General Electric Co., Bloomfield; res., East Orange, N. J.

BRIGGS, HARRY PHILLIP, Plant Engineer, Atlantic City Electric Co., Atlantic City, N. J.

BROWN, ERNEST KERESZTES, 311A Brighton Beach Ave., Brooklyn, N. Y.

CALVERT, FRANCIS, Student Erecting Engineer, Contract Service Dept., General Electric Co., Schenectady, N. Y.

CARTER, SIDNEY ERNEST CHARLES, General Tester, The New York Edison Co., 92 Vandam St., New York, N. Y.

CARVILL, ARTHUR LINCOLN, Electrical Engineer, Public Service Electric Co., 86 Park Place, Newark, N. J.

CLAPP, JEROME BASSETT, Engineer, Right-of-Way, Public Service Electric Co., 86 Park Place, Newark, N. J.
CLARK, HARVEY, Student, Drexel Institute, Philadelphia, Pa.
CLAYTON, HENRY MALONE, Acting Superintendent of Distribution, Arkansas Central Power Co., 4th & Louisiana Sts., Little Rock, Ark.
COON, IRA F., Electrical Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
CREED, EDWARD ST. CLAIR, Supt., Receiving Station, The Tata Hydro-Electric Power Supply Co., Ltd., Lalwadi P. O., Parel, Bombay, India.
DARST, JAMES M., Electrical Engineer, Electric Vacuum Cleaner Co., Inc., Ivanhoe Road & Euclid Ave., Cleveland, Ohio.
DA SILVA, PERY ROMA COELHO, Asst. Electrical Engineer, The Sao Paulo Tramway Light & Power Co., Ltd., Sao Paulo, Brazil, So. Amer.
FARISH, EDWARD T., 102 Jamaica Ave., Flushing, N. Y.
*FISKEN, JAMES B., Junior Electrical Engineer, The Washington Water Power Co., Spokane, Wash.
FRANKLIN, RAYMOND F., Electrical Engineer, General Electric Co., Schenectady; res., Scotia, N. Y.
FREY, JOHN NELSON, General Inspector, Westinghouse Elec. & Mfg. Co., Orange & Plane Sts., Newark, N. J.
GAUSZ, JOHN, Electrician, New York Edison Co., 130 E. 15th St., New York, N. Y.
GOLDSMITH, ELMER LE GRAND, Attorney at Law, 1212 Fletcher Trust Bldg., Indianapolis, Ind.
GOODYER, ARTHUR ANGRAVE, Commercial Representative, The Southern New England Telephone Co., 157 Church St., New Haven; res., West Haven, Conn.
GORDON, WILLIAM JOSEPH, Engineering Dept., Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.
GRAY, PETER FORSTER, Electrician, Canadian General Electric Co., 212 King St., W., Toronto, Ont. Can.
*GREENE, JAMES J., Meter & Tester Dept., United Electric Light & Power Co., 514 W. 147th St., New York, N. Y.
*HANCE, PAUL DEWITT, JR., Instructor, Machine Switching Dept., Western Electric Co., Inc., Hawthorne Works, Chicago; res., Elgin, Ill.
HANCOX, JACK CHARLES, Electrical Engineer, Borough Council, Lyttelton, N. Z.
HEARN, ROBERT J., Sales Student, Elec. Dept., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
HERBERT, E. S., Sales Engineer, Frankel Connector Co., 177 Hudson St., New York, N. Y.
HIRAMOTO, DAVID KOTOBUKI, Chief Electrician, Hawaiin Sugar Co., Makaweli, Kauai, Hawaii.
*HOILMAN, CHARLES W., Electrical Engg. Dept., General Electric Co., 2nd 64-G River Works, Lynn, Mass.
HOLST, LEIF JOHAN, Chief Manager, Electrical Works & Power Distribution, Drammen, Norway.
JOHNSON, JOHN ALEXANDER, Secretary-Treasurer & General Manager, Kuhlman Electric Co., Bay City, Mich.
JONES, FREDERICK ROBERT, Chief Ticker Inspector, Western Union Telegraph Co., 175 Congress St., Boston, Mass.
JUSELIUS, HARRY, Engineer, South Finland Interurban Telephone Co., Hogbergsg 37, Helsingfors, Finland.
KENNEDY, HERBERT SPENCER, Electrical Engineer, International Petroleum Co., Negritos, Talara, Peru, So. Amer.
KESTNER, PAUL WELTE, Engineer, Miniature Lamp Development Dept., Westinghouse Lamp Co., Bloomfield, N. J.
KIMMEL, JOSEPH JOHN, Electrical Testing Dept., Consolidated Gas, Electric Light & Power Co., Monument & Constitution Sts., Baltimore, Md.
KINNEY, HARVEY SMITH, Instructor, Electrical Engineering Dept., University of Nebraska, Lincoln, Nebr.
KNECHT, FRANK ANTHONY, Junior Electrical Engineer, Consolidated Gas & Electric Co., 1707 Lexington Bldg., Baltimore; res., Halethorpe, Md.
KRAMER, TRACY M., President, Sewickley Electric Mfg. Co., Sewickley, Pa.
KUKA, JAL MEHRJIBHAI, Electrical Engineer, The Tata Mills, Ltd., Dadar Road, Parel, Bombay, India.
*LANGE, HERBERT LEONARD, Inspector, Board of Fire Underwriters of the Pacific, Butte, Mont.
LEMANN, WILLIAM, 408 W. 49th St., New York, N. Y.
LYNCH, WILLIAM CHARLES, Manager, San Francisco Office, Aluminum Co. of America, 326 Rialto Bldg., San Francisco, Calif.
MACRINI, FRANCESCO, 1024 Cauldwell Ave., New York, N. Y.
MARCONI, CASIMIR GEORGE, Electrical Inspector, Elec. Construction Bureau, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn; res., New York, N. Y.
MARKUS, LOUIS, Electrical Engineer, 1102-53rd St., Brooklyn, N. Y.
MARTENS, CHRISTOPHER, Draftsman, Western Electric Co., Inc., 463 West St., New York, N. Y.
McILVAINE, EDGAR WATSON, Asst. to Commercial Supt., Allegheny Valley Light Co., 847-4th Ave., New Kensington, Pa.
MILNER, THOMAS CHRISTIAN, Operating Dept., Tugalo Power Plant, Georgia Railway Power Co., Tallulah Falls, Ga.
MOOREHOUSE, THOMAS, Master Mechanic, Lowell Gas Light Co., School & Rock Sts., Lowell, Mass.
MOREY, IRA, Sales Supervisor, New York Central Electric Corp., Hornell, N. Y.
*MURPHY, WILLIAM EDWARD, Owner, East End Electric Co., 380 Scott St., Wilkes-Barre, Pa.
NOEST, JOHN GEORGE, Operator, Brooklyn Edison Co., Inc., Hudson Ave. & East River, Brooklyn, N. Y.
NOLAN, THOMAS JOSEPH, System Opreator, Toledo Edison Co., Jefferson & Superior Sts., Toledo, Ohio.
OSWALD, CLARENCE M., Inspector, Westinghouse Elec. & Mfg. Co., 30th & Walnut Sts., Philadelphia, Pa.
OTT, ERWIN, Draughtsman, English Electric Co. of Canada, Ltd., St. Catharines, Ont., Can.
PHELAN, THOMAS E., Asst. Engineer, Radio Corp. of America, 66 Broad St., New York, N. Y.
PISANO, GAETANO HENRY, Fitter for Electrical Fixtures, Edward F. Caldwell & Co., Inc., 36-38, W. 15th St., New York, N. Y.
RAMSAY, HARRY BERTRAM, Junior Electrical Engineer, Phoenix Utility Co., 1804 Tchoupitoulas St., New Orleans, La.
REBMANN, PAUL COOPER, Vice-President, Franklin Porcelain Co., Norristown, Pa.
ROELLER, HAROLD CHRISTMAN, Electrical Foreman, Stanley G. Flagg & Co., Stowe; res., Pottstown, Pa.
RUTHERFORD, EDWIN JAMES, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.; res., Dunellen, N. J.
RYMES, CHARLES ERNEST, System Operator, Hydro-Electric Power Commission, Hydro, via Port Arthur, Ont., Can.
RYPINSKI, MILTON, Relay Tester, Brooklyn Edison Co., 14 Rockwell Place, Brooklyn, N. Y.
SCHOLEFIELD, PERCY WILLIAM, Manager, Transformer Dept., Brush Electrical Engineering Co., Ltd., Loughborough, Leicester, England.
SCOLA, BARTOLOMEO, 278-1st St., Brooklyn, N. Y.
SEALAMANDRE, FRANCO, Testing of Relays, Westinghouse Elec. & Mfg. Co., Newark, N. J.
*SHARMA, GYAN CHAND, Senior, Purdue University, West Lafayette, Ind.
SHIPP, ROY LOUIS, Superintendent, Guanajuato Power & Electric Co., Guanajuato, Gto. Mex.
SMITH, ALBERT BROKAW, Sales Engineer, American Brass Co., 25 Broadway, New York, N. Y.
SNYDER, WILLIAM BOWEN, Commercial Engineer, Industrial Engg. Dept., General Electric Co., Schenectady, N. Y.
SOULE, JULES FELIX, Electrician, Chicago Electric Co., 740 W. Van Buren St., Chicago, Ill.
SPARKS, SAMUEL WALTER, JR., Electrical Inspector, Duquesne Light Co., 702-A Chamber of Commerce Bldg., Pittsburgh, Pa.
STIMPSON, CLARENCE ARNEY, Salesman, Chicago Pneumatic Tool Co., 132 7th St., Pittsburg, Pa.
STRIKE, C. J., President, Consumers Electric Service Co.; Partner & Manager, Mid-West Electric Co., Webster, S. D.
TOMBLER, GEORGE EVERETT, Chief Electrician, Kueblers Foundries, Inc., Main & Dock Sts., Easton, Pa.
TORRES, TORIBIO ROLDAN, General Foreman, Mexican Light & Power Co., Planta Electrica, Indianilla, Mexico City, Mex.
VON BERNATH, LADISLAS, Engineer, Mexican Light & Power Co., 6A Versalles Num 106 B, Mexico, D. F., Mex.
*WALKER, EDMUND RHETT, Engineering Inspector, Brooklyn Edison Co., 561 Grand Ave., Brooklyn, N. Y.
WARD, RALPH B., Chief, Electrical Bureau, Dept. of Public Safety, City of Newark, City Hall, Broad St., Newark, N. J.
*WEBSTER, FRANCIS PHILANDER, Railway Electrification, Gibbs & Hill, Penn. Station New York; for mail, Brooklyn, N. Y.
WEISS, SIDNEY, Radio Engineer, Freed Eiseman Radio Corp., Sperry Bldg., Brooklyn, N.Y.
WELLWOOD, ROY MORIES, Electrician, Britannia Mining & Smelting Co., Britannia Beach, B. C., Can.
WENDT, MAX FREDERICK, Engineering Dept., Elevator Supplies Co., 1515 Willow Ave., Hoboken; res., Newark, N. J.
WILD, RUDOLF MAX, Electrical Draftsman, Stone & Webster, Inc., 147 Milk St., Boston, Mass.
WOOD, WILLIAM A., JR., Asst. Engineer, Cleveland Electric Illuminating Co., Illuminating Bldg., Cleveland, Ohio.

Total 90

*Formerly Enrolled Students

ASSOCIATES REELECTED AUGUST 12, 1924

BENEDICT, ERIC GEORGE, 43 Carver Road, Watertown Mass.
SILBERZVEIG, LEON, 1133 Broadway, New York, N. Y.
SMITH, ERIC WILBURN, Asst. Manager, General Electric Co., 1301 Pierce Bldg., St. Louis, Mo.
WATTS, FRANK WILMER, Consulting Engineer, 1622 You St., N. W., Washington, D. C.

MEMBERS ELECTED AUGUST 12, 1924

CLEMINSHAW, RUSSELL H., Chief Engineer, Cleveland Electric Motor Co., 5213 Windsor Ave., Cleveland, Ohio.
CURRAN, ROBERT W., General Superintendent, Portsmouth Public Service Co., Portsmouth, Ohio.
DEL CORRAL, MARTIN, Chief Engineer & General Manager, Vicente B. Villa & Co., 84 Broad St., New York, N. Y.
DENZLER, MAX FELIX, American Representative, Brown, Boveri & Co., Ltd., Baden, Switzerland; Electrical Engineer, Engg. Dept., Scintilla Magneto Co., 225 W. 57th St., New York, N. Y.

EDWARD, GEORGE W., President & General Manager, Morganite Brush Co., Inc., New York, N. Y.
GRAY, WILLIAM REED, Production Manager, The Eppley Laboratory, 12 Sheffield Ave., Newport, R. I.
LESSER, WILLIAM HENRY, Mechanical Engineer, Madeira Hill & Co., Frackville, Pa.
OBOUKHOFF, NICOLAS MICHAILOVICH, Professor of Electrical Engineering, The Russian Chinese Polytechnic Institute, 21 Pravlenskaya St., Harbin, Manchuria, China.
PACKARD, ROLAND A., Mechanical Engineer, Ludlow Mfg. Associates, 7 Park Pl., Ludlow, Mas..

TRANSFERRED TO GRADE OF MEMBER AUGUST 12, 1924

JONES, BENSON M., Switchboard & Control Engineer, Duquesne Light Co., Pittsburgh, Pa.
MOSSAY, PAUL A., Consulting Electrical Engineer, London, England.
SHULER, WILLIAM, Electrical Engineer, Dayton Power & Light Co., Dayton, Ohio.
THORMAHLEN, ARTHUR, Plant Engineer, Durant Motors of Canada, Leaside, Ont.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1924.

Alexander, T. W., Jr., The Bell Tel. Co. of Pa., Pittsburgh, Pa.
Aronoff, S., Union Gas & Electric Co., Cincinnati, Ohio
Ayvasian, M. H., Edison Electric Ill. Co. of Boston, Boston, Mass.
Barr, J. H., Stone & Webster, Boston, Mass.
Battista, L. M., Tidewater Building Corp., Farmington, Conn.
Burchett, C. W., Theatre Equipment Supply Co., San Francisco, Calif.
Cahoon, A. W., Penn Public Service Corp., Johnstown, Pa.
Campbell, W. Ross, Kansas City Power & Light Co., Kansas City, Mo.
Carl, R. D., Philadelphia Electric Co., Philadelphia, Pa.
Carmody, R. P. M., Buffalo Steel Car Co., Inc., Buffalo, N. Y.
Carno, S., (Member), 165 Jerome St., Brooklyn, N. Y.
Church, J. O., Walsh & Weidner Boiler Co., Chattanooga, Tenn.
Clark, F. M., General Electric Co., Pittsfield, Mass.
Cobb, L. H., Cushman & Wakefield, New York, N. Y.
Coxe, E. H., Jr., Duquesne Light Co., Pittsburgh, Pa.
Defeo, J. C., 18 Ward St., Paterson, N. J.
Doobin, A. M., 1770 Madison Ave., New York, N. Y.
Eggenberger, J. B., United Electric Light & Power Co., New York, N. Y.
Featherstone, E. B., Teacher, Scott & Libbey High Schools, Toledo, Ohio
Fife, H. A., Commonwealth Edison Co., Chicago, Ill.
Geesaman, J. E., Jr., Electrical Contractor, Shippensburg, Pa.
Goldiner, A. C., 246 Prospect Park West, Brooklyn, N. Y.
Hallowell, E. M., Delta Star Electric Co., Chicago, Ill.
Hanson, E. C., Student, Dixville, Quebec, Can.
Herrschaft, W., Chicago School of Elec., Div., School of Engg. of Milwaukee, Wis., Chicago, Ill.
Hincy, W. A., Drexel Institute, Philadelphia, Pa.
Hodgson, E., Marconi Wireless Telegraph Co. of Canada, Ltd., Montreal, P. Q., Can.
Hoff, N. S., The Bell Tel. Co. of Pa., Pittsburgh, Pa.
Holmes, J. T., (Member), I. P. Frink, Inc., New York, N. Y.
Hoppesch, J. W., Western Electric Co., Inc., Chicago, Ill. Concordia College, River Forest, Ill.
Hynes, L. P., (Member), Hynes & Cox Electric Corp.; Consolidated Car Heating Co., Albany, N. Y.
Irish, F. M., Colorado Power Co., Denver, Colo.
Junkins, A. B., (Member), American Sugar Refining Co., Baltimore, Md.
Kowalski, E. W., The Washington Water Power Co., Pullman, Wash.
Kundts, R. H., Columbus Railway, Power & Light Co., Columbus, Ohio
Little, D. S., Radio Corp. of America, Chicago, Ill.
Magee, C. W., 32 Undercliff St., Yonkers, N. Y.
Millman, M., 25 Barrett St., Brooklyn, N. Y.
Mitchell, D. H., A. T. & S. F. Railroad, Shopton, Iowa
Myers, V. E., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Neher, J. H., Philadelphia Electric Co., Philadelphia, Pa.
Nichols, A. G., Public Service Production Co., Newark, N. J.
Nicholson, G. C., General Electric Co., Schenectady, N. Y.
Olson, S. G., Pacific Gas & Electric Co., San Francisco, Calif.
Osborne, J. I., American Smelting & Refining Co., Maurer, N. J.
Parmley, S., Electrical Contracting, Gary, Ind.
Pixler, J., Jr., 7115 Calumet Ave., Chicago, Ill.
Querques, A., Public Service Production Co., Newark, N. J.
Richmond, H. S., Columbus Railway, Power & Light Co., Columbus, Ohio
Risley, R. L., (Member), Electrician, Kingston, N. Y.
Robertson, W. G., General Electric Co., New York, N. Y.
Rogers, P. L., Asst. to H. Berkeley Hackett, Philadelphia, Pa.
Ross, T. A., (Member), Guaranty Trust Co., New York, N. Y.
Salerno, A. A., Consolidated Tel. & Elect. Subway Co., New York, N. Y.
Santos, B., Rio Piedras, Porto Rico
Schaffer, J. H., Thomas E. Murray, Inc., Bronx, N. Y.
Schreader, A. H., Electrical Contractor, Clayton, Mo.
Sharman, F. H., Pullman Co., New York, N. Y. (Applicant for re-election)
Solberg, J. S., Gibbs & Hill, New York, N. Y.
Spratt, W. W., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Stock, H. F., Acme Electric Co., Kansas City, Mo.
Stocker, L. J., Public Electric & Gas Co., Trenton, N. J.
Sward, C. W., G. & W. Electric Specialty Co., Chicago, Ill.
Van Kuran, K. E., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
(Applicant for re-election.)
Weeks, J. L., Jr., Western Electric Co., Inc., New York, N. Y.
White, H., American Electric Co., St. Joseph, Mo.
Wieland, H. G., New York Edison Co., New York, N. Y.
Wu, W. C., Commonwealth Power Corp., Jackson, Mich.
Zipse, A. E., G. & W. Electric Specialty Co., Chicago, Ill.

Total 68

Foreign

Arai, K., Mitsubishi Electrical Engineering Co., Kobe, Japan
Asai, T., Mitsubishi Electrical Engineering Co., Kobe, Japan
Carson, A. H., Posts & Telegraphs Dept., Kuala Lumpur, Federated Malay States.
Evans, W. R., Vacuum Oil Co., Melbourne Victoria, Aus.
Hahn, O. H., Siemens (S. A.) Ltd., Johannesburg, S. Africa
Hughes, G. A. F., Metropolitan Vickers Elec. Co., Manchester, En
Nakazato, R., Mitsubishi Electrical Engineering Co., Koke, Japan
Parry, W., The English Electric Co., Ltd., Stafford, Eng.
Takahashi, M., Ministry of Communications, Tokyo, Japan
Tanaka, K., Mitsubishi Electrical Engineering Co., Kobe, Japan
Tikuma, T., Shibaura Engineering Works, Tokyo, Japan
Wigan, L. J. C., Adelaide Electric Supply Co., Ltd., Adelaide, S. Australia; London, Eng.

Total 12

STUDENTS ENROLLED AUGUST 12, 1924

19070 Ararpakis, George H., Mass. Institute of Technology
19071 Cotner, Walter W., Ohio Northern Univ.
19072 Heseltine, Robert G., Worcester Polytechnic Institute
19073 Gialias, George E., Brooklyn Polytechnic Institute
19074 Johnson, Edwin E., University of Wisconsin
19075 Hattori, Rai, Harvard University
19076 Horko, William N., Drexel Institute
19077 Newman, Harry J., University of Colorado
19078 Dehlendorf, Robert O., Mass. Institute of Technology
19079 Sanford, Frank E., Univ. of Cincinnati
19080 Barrett, Francis A., Mass. Inst. of Tech.
19081 Demestre, Luis F., Havana University
19082 del Campo y Ferrer, Armando, Havana University
19083 Laycock, Thomas A., Rhode Island State College
19084 Karman, Raoul, Havana University
19085 Gross, George J., Mass. Inst. of Technology
19086 Peterson, Hugo A., Tri-State College
19087 Richardson, Benjamin P., Jr., Mass. Inst. of Technology
19088 Brown, Edwin S., Drexel Institute
19089 Law, Theodore R., Tri-State College
19090 Kleckner, Marion B., The Municipal University of Akron
19091 Etter, Clyde M., Tri-State College
19092 Gada, Natale, Mass. Inst. of Technology
19093 Rockwood, George H., Jr., Mass. Inst. of Technology
19094 Larson, Hans E., Univ. of Southern Calif.
19095 Humphries, Powell H., Harvard Univ.
19096 Hammar, Ralph A., Mass. Inst. of Tech.
19097 Wood, Eugene W., Mass. Inst. of Tech.
19098 Schilling, Ernest R., Cornell University
19099 Taylor, Louis R., Mass. Inst. of Technology
19100 Freret, Lawrence L., Alabama Poly. Inst.

Total 31

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held July 31, 1924, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

HOBBINS, WILLIAM D., Chief Engineer, Wisconsin Telephone Co., Milwaukee, Wis.
WILLEY, FRANK W., Member of Firm, Willey Wray Electric Co., Cincinnati, Ohio

To Grade of Member

GOFF, HAROLD W., Designing Engineer, Western Electric Co., New York, N. Y.
KNAPP, PETER R., Assistant Superintendent, Electric Department, Toledo Edison Co., Toledo, Ohio
SCHWABE, WALTER P., Vice-President & General Manager, Northern Connecticut Light & Power Co., Thompsonville, Conn.
SMITH, WALTER H., Railway Equipment Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Officers A. I. E. E. 1924-1925

PRESIDENT
(Term expires July 31, 1925)
FARLEY OSGOOD

JUNIOR PAST-PRESIDENTS

(Term expires July 31, 1925)
FRANK B. JEWETT

(Term expires July 31, 1926)
HARRIS J. RYAN

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(Terms expire July 31, 1925)
J. E. MACDONALD (District No. 8)
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S.E.M.HENDERSON (District No.10)
H. E. BUSSEY (District No. 4)
WILLIAM F. JAMES (District No. 2)

(Terms expire July 31, 1926)
EDWARD BENNETT (District No. 5)
JOHN HARISBERGER (District No. 9)
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L. F. MOREHOUSE (District No. 3)
H. W. EALES (District No. 7)

MANAGERS

(Terms expire July 31, 1925)
R. B. WILLIAMSON
A. G. PIERCE
HARLAN A. PRATT

(Terms expire July 31, 1926)
H. M. HOBART
ERNEST LUNN
G. L. KNIGHT

(Terms expire July 31, 1927)
WILLIAM M. McCONAHEY
W. K. VANDERPOEL
H. P. CHARLESWORTH

(Terms expire July 31, 1928)
JOHN B. WHITEHEAD
J. M. BRYANT
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TREASURER **SECRETARY**
(Terms expire July 31, 1925)
GEORGE A. HAMILTON F. L. HUTCHINSON

HONORARY SECRETARY
RALPH W. POPE

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PARKER & AARON
30 Broad Street, New York.

PAST-PRESIDENTS—1884-1924

*Norvin Green, 1884-5-6.
*Franklin L. Pope, 1886-7.
*T. Commerford Martin, 1887-8.
Edward Weston, 1888-9.
Elihu Thomson, 1889-90.
*William A. Anthony, 1890-91.
*Alexander Graham Bell, 1891-2.
Frank Julian Sprague, 1892-3.
*Edwin J. Houston, 1893-4-5.
*Louis Duncan, 1895-6-7.
*Francis Bacon Crocker, 1897-8.
A. E. Kennelly, 1898-1900.
Carl Hering, 1900-1.
*Charles P. Steinmetz, 1901-2.
Charles F. Scott, 1902-3.
Bion J. Arnold, 1903-4.
John W. Lieb, 1904-5.
*Schuyler Skaats Wheeler, 1905-6.
*Samuel Sheldon, 1906-7.
*Henry G. Stott, 1907-8.
Louis A. Ferguson, 1908-9.
Lewis B. Stillwell, 1909-10.
Dugald C. Jackson, 1910-11.
Gano Dunn, 1911-12.
Ralph D. Mershon, 1912-13.
C. O. Mailloux, 1913-14.
Paul M. Lincoln, 1914-15.
John J. Carty, 1915-16.
H. W. Buck, 1916-17.
E. W. Rice, Jr., 1917-18.
Comfort A. Adams, 1918-19.
Calvert Townley, 1919-20.
A. W. Berresford, 1920-21.
William McClellan, 1921-22.
Frank B. Jewett, 1922-23.
Harris J. Ryan, 1923-24.

*Deceased.

LOCAL HONORARY SECRETARIES

T. J. Fleming, Calle B. Mitre 519, Buenos Aires, Argentina, S. A.
Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janeiro, Brazil, S. A.
Charles le Maistre, 28 Victoria St., London, S. W., England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
H. P. Gibbs, Tata Sons Ltd., 24 Bruce Road, Bombay—1, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
Eiji Aoyagi, Kyoto Imperial University, Kyoto, Japan.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

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Chairman of Sections Committee.
Chairman of Publication Committee.
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BOARD OF EXAMINERS

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F. M. Farmer, W. I. Slichter.

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C. E. Magnusson, Vice-Chairman
A. W. Berresford, H. H. Henline, Herbert S. Sands.
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F. S. Dellenbaugh, Jr., C. Francis Harding, Harold B. Smith.
Charles F. Scott,

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C. E. Fleager, E. B. Meyer J. F. Warwick,
S. E. M. Henderson, L. S. O'Roark J. L. Woodress.
A. L. Penniman,
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R. F. Schuchardt,

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Gano Dunn, John W. Lieb, Harris J. Ryan,

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A. H. Babcock, L. F. Morehouse, H. S. Wynkoop.
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Washington, State Coll. of, Pullman	J. Dunkin	J. T. Yasumura
Washington Univ., St. Louis, Mo.	H. Spoehrer	C. M. Dunn
Washington, Univ. of, Seattle, Wash.	John Weir	J. W. Lewis
West Virginia Univ., Morgantown	O. A. Brown	James Copley
Wisconsin, Univ. of, Madison, Wis.	H. G. Holmes	K. E. Wooldridge
Yale Univ., New Haven, Conn.	W. C. Downing, Jr.	O. B. Skinner
Total 77		

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Meters for Train Lighting.—Bulletin, 16 pp. Describes "Sangamo" amperehour meters for train lighting systems, of a new and much improved type. Sangamo Electric Company, Springfield, Ill.

Polyphase Motors.—Bulletin 35, 12 pp. Describes a complete line of squirrel-cage induction polyphase motors manufactured in sizes from $^1/_6$ to 75 hp. Century Electric Company, St. Louis, Mo.

Centrifugal Pumps.—Bulletin 1632-G, 58 pp. Describes "A-C" centrifugal pumps and pumping units for power plants, and a wide variety of industrial purposes. Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

Boilers.—Bulletin. Describes the new Union "Universal" boiler of the self-contained return flue type. The boiler is made in sizes from 25 to 150 hp. and is particularly adapted to installations where only small floor space is available. Union Iron Works, Erie, Pa.

Theatre Light Control.—Bulletin 62, 12 pp. Describes the "Controlite," a simple, compact switchboard and dimmer bank in one assembly whereby the operator controls the lighting effects by the operation of one handle. Ward Leonard Electric Company, Mount Vernon, N. Y.

Synchronous Motors.—Bulletin 854, 12 pp. Describes the "E-M" line of synchronous motors for compressors, and contains illustrations of representative installations. A list of some of the users is given in Bulletin 785. Electric Machinery Mfg. Company, Minneapolis, Minn.

Steam Condensers.—Bulletin 1662, 44 pp. Describes Westinghouse steam condensers of the surface, low level jet, and barometric types, as well as auxiliary equipment, including air removal apparatus, pump drives, motors, and control equipment. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Thrust Bearings.—Bulletin D. Describes Kingsbury thrust bearings, vertical equalizing types, giving the dimensions, capacities and mountings. Such bearings are applicable in hydraulic turbines, vertical motors, generators, etc. Kingsbury Machine Works, 4320 Tackawanna Street, Frankford, Philadelphia, Pa.

Meter Testing Devices.—Booklet, 36 pp., "Meterology." The booklet has been compiled for the convenience of meter men and contains practical data on meter and switchboard installations. Describes the meter testing devices, switches and panelboards manufactured by the Superior Switchboard & Devices Company, Canton, Ohio.

Gears.—Catalog 29, 224 pp. Describes a complete line of gears, which includes every kind, shape and manner of gear; spur gear speed reducers, and worm gear drives. Materials from which the gears are made include cast iron, cast steel, forgings, rawhide and bakelite. W. A. Jones Foundry & Machine Company, 4401 West Roosevelt Road, Chicago, Ill.

Magnetic Switch.—Bulletin 105, 4 pp. Describes the Monitor "Triplock" Switch, an electrically operated, mechanically locking, double-pole switch which cuts off its own operating current as soon as a closing or opening movement of the switch is completed, for use in remote control of lighting circuits and electrical apparatus. Monitor Controller Company, 500 E. Lombard St., Baltimore, Md.

Transformers.—Bulletin 2032, 4 pp. Describes mechanical and electrical design of "Pittsburgh" transformers. Bulletin 2033, 4 pp., describes distributing transformers, single-phase and polyphase. Bulletin 2034, 4 pp. describes 10,000 kv-a. transformers recently constructed, outlining some of the special features of polyphase design; also describing the advantages of the new "Pittsburgh" radiator. Pittsburgh Transformer Company, Columbus & Preble Aves., Pittsburgh, Pa.

Index to G-E Publications.—Bulletin Y-1991. Lists all publications describing the products of General Electric Company, Schenectady, N. Y.

NOTES OF THE INDUSTRY

The Belden Manufacturing Company, manufacturers of insulated wire, cable and cordage, has removed its eastern sales office and warehouse from Metuchen, N. J., to 399 Market St., Newark, N. J. The new location is conveniently located one block from the Pennsylvania R. R. Station. In this warehouse greatly increased and more varied stocks of magnet wire, rubber covered wire and insulation material will be carried for the requirements of the eastern trade. S. C. Schenck continues in charge.

L. G. LeBourveau has been appointed southeastern representative of the Belden Company, with headquarters at 708 W. 29th Street, Jacksonville, Fla.

Wagner Electric Corporation, St. Louis, Mo.—The appointment of E. W. Goldschmidt as eastern executive representative of the company, with headquarters in New York, and of Alex. Miltenberger as western executive representative with headquarters in San Francisco, has been announced. Mr. Goldschmidt has been associated with the Wagner Company for twenty-three years, the last twenty-two of which he has been district sales manager in New York. In his new position Mr. Goldschmidt will be primarily responsible for the relations of the Wagner Company with central station companies throughout the eastern part of the country, and particularly for cooperation with those companies in the matter of power factor research and correction; the Wagner Company, as manufacturers of the Fynn-Weichsel motor, having a particularly keen interest in this subject.

Joseph C. Bowman, Advertising Manager of the Packard Electric Company, will establish his own agency in Cleveland, after September 1st. The Packard Company has contracted with Mr. Bowman to direct its advertising for the next five years.

Indoor Radio Aerial.—The Hope Webbing Company, Providence, R. I., will shortly market a new material, "Talking Tape," a woven combination of metallic strands and fibre for use in indoor radio aerials. Due to its maximum receptive surface, and an extremely low resistance, unusually high sensitivity in radio reception is claimed for the new product.

Paper Pulleys.—The Best Pulley Manufacturing Company, St. Louis, Mo., is producing a new line of paper pulleys made of a specially treated paper fibre, hydraulically compressed into a solid block. The end grain of the fibre is exposed to the belt and grips without slippage. A feature of these pulleys is a new patented double locking hub which has three sets of two ribs each, which grip into the paper and prevent the hub from becoming loose, even though the pulley may be reversed in direction. The pulleys are made in 2500 stock sizes.

Eric Wilburn Smith, central station salesman and assistant manager of the General Electric Company, St. Louis, has joined the staff of Ray D. Lillibridge, Inc., engineers and general advertising agents, New York City. Mr. Smith will devote himself particularly to the interest of this agency's clients in the light and power industry, among whom are the Wagner Electric Corporation, of St. Louis; Sangamo Electric Company, of Springfield, Illinois; Monitor Controller Company, of Baltimore; Kerite Insulated Wire & Cable Company of New York; Ward Leonard Electric Company, of Mount Vernon, N. Y.; Heine Boiler Company, of St. Louis; the Hoover Company, of North Canton, Ohio; Chase Metal Works and Waterbury Brass Company, of Waterbury, Conn., and the Worthington Pump and Machinery Corporation, of New York.